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A Decision-Making Framework for Residential Construction Waste Reduction in New Zealand

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Doctor of Philosophy (PhD)

Abstract

The high rate of construction waste (CW) sent to landfills is a growing challenge to New Zealand's commitment to achieving strategic goals on waste management and climate change action. Simultaneously, the residential construction sector in New Zealand and worldwide is experiencing increased criticism about generating the highest levels of CW due to the continuous surge in residential construction demand. Despite some success in managing CW, factors that influence decision-making in CW reduction effectively and sustainably are yet to be thoroughly investigated. Accordingly, the research aims to develop a decision-making framework to support residential construction waste reduction (RCWR) in New Zealand. The conceptual research framework focuses on the factors influencing RCWR in New Zealand, along with an emphasis on the interrelationship among influencing factors to inform strategic resource allocation and prioritise aspects of RCWR. The research design employed a sequential, exploratory, mixed-methods approach. Initially, the literature review identified the concepts related to RCWR and the key stakeholders involved in the decision-making process. Following this, interviews with subject matter experts were conducted to define and categorise the factors comprehensively. This foundation directly informed the development of the survey questions, which were subsequently refined using quantitative partial least squares-structural equation modelling (PLS-SEM). The qualitative research contributed to the development of the theoretical model, while the quantitative analysis helped refine it statistically. Additionally, the multi-criteria decision-making (MCDM) framework validated that the model effectively measured the practical aspects for decision-makers using the combined techniques of fuzzy technique for order of preference by similarity to ideal solution (TOPSIS) and fuzzy decision-making trial and evaluation laboratory (DEMATEL). Results from the interviews revealed 25 factors into eight categories: operational, governance, economic, innovative and technical, social and behavioural, environmental, process and procedures, and organisational. A significant finding was that efforts in RCWR would be significantly enhanced if manufacturers and suppliers took responsibility for the end-of-life management of their products. The developed decision-making framework proposed critical strategies to optimise RCWR, including collaboration and communication, convenient approaches, incentives and recognition, education, waste infrastructure, circular materials, and takeback schemes. Research outcomes contribute to providing insights into RCWR, promoting collaboration among the key stakeholders, and understanding constraints and priorities for RCWR in New Zealand. Furthermore, the decision-making tool is expected to enable decision-makers to design strategies and policies that optimise RCWR and help New Zealand achieve its goals of transitioning to a circular economy, meeting emissions reduction targets, and fulfilling the United Nations (UN) Sustainable Development Goals (SDGs).

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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, nor used artificial intelligence tools or generative artificial intelligence tools, nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.

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Co-Authored Works and Declaration of Collaboration

Statement from co-authors confirming the authorship contribution of the PhD candidate: As co-authors of the research "A Decision-making Framework for Residential Construction Waste Reduction in New Zealand", we confirm that Hadeel Albsoul contributed over 80% of the research. Hadeel Albsoul is responsible for writing, ideas, and the content of the research. Supervisors Dr Dat Tien Doan, Dr Itohan Esther Aigwi, and the mentor, Prof. Ali GhaffarianHoseini, provided guidance and peer review to improve the quality of the research.

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List of Publications

Journal Articles

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Conference Proceedings

Albsoul, H., Doan, D. T., Aigwi, I. E., & GhaffarianHoseini, A. A Review of Residential Construction Waste Reduction. Perera, S., & Hardie, M. (2022), Global Challenges in a Disrupted World: Smart, Sustainable and Resilient Approaches in the Built Environment. *Proceedings of the 45th AUBEA Conference*, Western Sydney University, Australia, November 23-25, 2022 (523-532).

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List of Abbreviations

BIM	Building Information Modelling
CW	Construction Waste
DEMATEL	Decision-Making Trial and Evaluation Laboratory
EPD	Environmental Product Declaration
GDP	Gross Domestic Product
GHG	Greenhouse Gas
IRM	Influence-Relation Map
RCWR	Residential Construction Waste Reduction
PLS	Partial Least Squares
SEM	Structural Equation Modelling
SDG	Sustainable Development Goal
SLR	Systematic Literature Review
3DP	Three-Dimensional Printing
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
LCA	Life Cycle Assessment
OECD	Organisation for Economic Cooperation and Development
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
MCDM	Multi-Criteria Decision Making
WMP	Waste Management Plan

Chapter 1 Introduction

1.1 Overview

This chapter presents a concise overview of the thesis. It commences by introducing prior literature to underscore the significance of this research and the necessity for further exploration in this domain. Subsequently, it identifies the gaps in the existing literature and outlines the research's aims and objectives, along with a description of the research methods used. Furthermore, it highlights the contributions of this research to both academia and the construction industry. Finally, it provides a brief summary of the thesis structure and outlines the subsequent chapters.

1.2 Trends in Construction Waste (CW)

Across the world, there are considerably rising concerns about waste generated from construction activities and the associated environmental impacts, mainly climate change, raw material depletion and released emissions. Waste is categorised and characterised differently based on the type of sources and activities (i.e. construction, demolition, and renovation) (Sivashanmugam et al., 2023). CW occurs during the planning, design, site work, and delivery stages of the construction project (Ajayi, Oyedele, Akinade, Bilal, Alaka, & Owolabi, 2017). Understanding the characteristics of different types and causes of CW is essential for optimising management strategies and improving operational efficiency (Gulghane & Khandve, 2015; Hwang & Bao Yeo, 2011). For instance, in China, the waste generated from construction activities form up to 40% of the total waste and 30% of greenhouse gas (GHG) emissions (Mao et al., 2013; Wang, Zhang, & Wang, 2018). In the UK, the residential construction sector generates approximately a third of total waste and 30% of total carbon emissions annually, contributing significantly to global climate change and depletion of resources (Cuéllar-Franca & Azapagic, 2012).

Climate change has an inverse effect on the future of the built environment by causing further waste due to severe weather conditions (Hurlimann, Warren-Myers, & Browne, 2019; Nagapan et al., 2012). Countries with large-scale developments, like Australia, the UK, and China, have established CW management as a critical focus to improve the environmental impact of construction activities (Li et al., 2020; Ma et al., 2020). These countries have implemented sustainable construction practices, enacted regulatory frameworks and developed markets for recycled materials to reduce CW and promote resource efficiency (Chi et al., 2020; Umar et al., 2017). At the project level, developing a site waste management plan has been made compulsory in the UK to support the European Commission's efforts on waste reduction (Shiers et al., 2014). In contrast, Australia's national waste policy emphasises waste reduction and sustainable construction through a circular economy approach aiming to enhance waste diversion and material reuse and recovery (Kempton, Boehme, & Amirghasemi, 2024). Meanwhile, the US and China have established regional and national policies, invested in market development for recycled materials, and employed sustainable and innovative construction methods, including green building and design for deconstruction (Aslam, Huang, & Cui, 2020; Chi et al., 2020). These measures underscore a collective global commitment to reducing CW through policy, innovation, and a transition towards sustainable and circular construction.

According to the Ministry for the Environment- MfE (2021b), CW forms 50% of the total waste in landfills across New Zealand. Landfilling is the most customary practice for managing waste in New Zealand (New Zealand Infrastructure Commission, 2023). Disposing of CW to landfills maximises threats to sustainability, creating several environmental concerns, including pollution (water, air, and land), landfill space degradation, natural resources depletion, and climate change (Crawford, Mathur, & Gerritsen, 2017; Umar, Shafiq, & Isa, 2018; Wang et al., 2018). In addition to the adverse environmental effects, CW has an economic cost due to the building material loss and is a source of risks to workers on construction and waste disposal sites (Construction Sector Accord, 2021).

New Zealand, as a signatory member in the international action for climate change “Paris Agreement”, is committed to developing sustainable measures for waste management. National targets defined by the Ministry for the Environment- MfE (2023a) include reducing GHG by 30% and below 2005 levels by 2030. This agreement was signed in 2015 and commissioned in 2021. Statutory requirements support waste reduction at the government (central and local) and industry levels. The primary legislative control for waste in New Zealand is the Waste Minimisation Act (2008), which makes planning and reporting on waste management mandatory. While the Building Act (2004) also ensures the need to facilitate CW reduction during the construction process; the effectiveness of these pieces of legislation is limited and is currently being reviewed (Ministry for the Environment- MfE, 2023b).

1.3 Conceptualising Residential Construction Waste Reduction (RCWR)

The escalating growth in demand for residential construction is associated with a substantial amount of waste generation (Duan et al., 2019). Thus, establishing the link between the historically growing residential construction work value and the increasing share of discarded CW in landfills is of the essence. There is an urgent need to manage CW in the residential construction sector due to the continuous surge in residential construction demand, higher levels of generated CW, and the ongoing environmental impacts. Accordingly, CW reduction is the most optimal waste management strategy in the 3R’s principle of reducing, reusing, and recycling wastes (Wang, Li, & Tam, 2015).

The term “waste reduction” is frequently used with the summarised version of the waste hierarchy: the 3R principle of reduce, reuse, and recycle (Van Ewijk & Stegemann, 2016). However, literature on waste management uses the term “waste reduction” synonymously with the terms “waste avoidance” (Wu et al., 2016) and “waste minimisation” (Ugwu et al., 2021). The interpretation of the waste hierarchy varies among multiple users, particularly government, industry, researchers, and environmental groups (D’Inverno, Carosi, & Romano, 2024). Similarly, Lv et al. (2021) revealed that countries adopt different waste hierarchies by applying the most preferred waste management approach with a common goal of maximising the environmental benefits. The study indicates that “waste reduction” has been referred to as “source reduction”, “prevention”, and “prevention and minimisation”, respectively at the United States, the European Commission, and Hong Kong waste hierarchies. Lv et al. (2021) concluded that both terms “minimisation” and “prevention” are attributed to waste reduction at the source.

Despite the controversial use of different terms, the 3R principle is the primary guidance for CW management practices (Huang et al., 2018). In New Zealand, the term "waste reduction" is embedded in the Waste Minimisation Act (2008), explicitly stating that "waste minimisation is the reduction of waste” and waste reduction is "lessening waste generation". Additionally, "waste reduction" is regarded as the focus of New Zealand's work on CW (Ministry for the Environment- MfE, 2023b). Therefore, following New Zealand's interpretation, CW reduction is the preferred term for this research.

The rate of waste disposal in landfills in New Zealand has been increasing rapidly, with an estimated rise of 48% over the last decade (Ministry for the Environment- MfE, 2019), particularly in regions experiencing higher levels of construction activities due to population growth and housing demand. The most recent waste reports from several local councils, such as Auckland Council (2024b), Wellington City Council (2023), Hamilton City Council (2024), Dunedin City Council (2020), and Tauranga City Council (2022), highlight CW as one of the most challenging waste streams. They estimate that CW will continue to increase due to accelerated residential construction activities driven by population growth in these regions. These councils have set common vital objectives and challenges for future work on CW, as illustrated in Figure 1.1.

Figure 1.1: Shared goals and challenges for waste management and reduction plans in different regions of New Zealand (Adapted from: Wellington City Council (2023); Tauranga City Council (2022); Hamilton City Council (2024); Dunedin City Council (2020); Auckland Council (2024b))

Most developed countries, including Australia, Canada, China, the UK, and New Zealand, have adopted building legislation to promote sustainability and waste reduction in the built environment (Enker & Morrison, 2020; Meacham, 2010). Furthermore, CW reduction strategies, policies, and plans have been proposed in Australia (Li, Li, & Du, 2015), the European Commission (Gálvez-Martos et al., 2018), and China (Liu, Yi, & Wang, 2020). However, achieving CW reduction remains a significant concern in practice and theory (Viswalekshmi, Bendi, & Opoku, 2023).

Researchers have thus devoted increasing efforts to advancing knowledge in CW reduction. Numerous studies have been conducted with a central concern on enabling the adoption of CW reduction, often in one stage of construction. While some studies, such as Osmani, Glass and Price (2008), Ding et al. (2018), and Banihashemi, Tabadkani and Hosseini (2018) have explored improving CW reduction in the design stage. Alternatively, Abarca-Guerrero, Maas and Van Twillert (2017) highlighted how conventional construction methods and practices impede successful CW reduction. Therefore, there is a need to explore emerging approaches to reducing CW and comprehend the potential benefits and barriers of integrating such approaches in the residential sector.

Waste reduction is the prime focus of New Zealand's quest to transition into a circular economy and emission reduction target (Ministry for the Environment- MfE, 2023b). The waste strategy prioritises CW as a significant, challenging waste stream in New Zealand (Ministry for the Environment- MfE, 2023b). Extreme environmental impacts and proposed regulatory changes have prompted the construction industry to implement waste reduction in the industry's management programs, aligning with government objectives (Construction Sector Accord, 2021). According to a report published by the Building Research Association New Zealand- BRANZ (2021), in partnership with the construction sector accord, the environmental roadmap for the construction sector seeks to support firms in the industry in adopting sustainable construction approaches to overcome environmental challenges. This indicates a joint agreement that current conventional practices in residential construction are incompatible with the goal of CW reduction and the transition to a circular economy.

Voluntary tools are available for the construction industry in New Zealand to enhance their contribution to RCWR, including (ii) the resource efficiency in the building and related industries (REBRI) guide that provides case studies and guidance on planning for CW reduction (Building Research Association New Zealand-BRANZ, 2024); (ii) Eco Choice Aotearoa (2024) which provides a guide on materials with better environmental specifications and ecolabelling that enable CW operators and developers to track CW and assess the environmental impact of the product lifecycle; and (iii) a Homestar rating tool designed by the New Zealand Green Building Council-NZGBC (2023). The Homestar is a rating framework that evaluates the sustainability of residential design and construction according to several categories, including waste management.

To understand this research area in New Zealand, "Construction waste" AND "reduction" AND "New Zealand" are the keywords used to find publications using the Scopus database outlining CW reduction in New Zealand. Only two publications resulted: Luo and Shahzad (2020) and Purushothaman and Seadon (2020). The exact search was conducted using the Google Scholar database, and only papers relevant to CW reduction were selected. 20 publications, including conference papers, journal papers, a report, and a guide, were found in the New Zealand context from 2005 through 2021. Most studies examined the application of emerging technology, sustainable approaches, and construction practices in improving CW reduction.

Although a few studies have attempted to explore CW reduction in New Zealand, the number of publications and conferences has been progressively increasing. According to Table 1.1, the number of publications was the highest in 2020, with two journal papers and six conference papers. However, there are only ten journal papers out of the 20 other publications, with most of the remaining being conference papers. The jumped rise in conference publications in 2020 could be attributed to holding the “New Zealand Built Environment Research Symposium (NZBERS 2020)” at Massey University, New Zealand, and the “International Conference of Architectural Science Association (ANZAScA)” at Auckland University of Technology, New Zealand. This indicates a growing interest among the research community in New Zealand in CW management.

Table 1.1: Publications outlining CW reduction in New Zealand

No.	Title	Category	Reference
1	Construction waste modelling for residential construction projects in New Zealand to enhance design outcomes	Journal	Domingo and Batty (2021)
2	At what cost? An analysis of the green cost premium to achieve 6-Homestar in New Zealand	Journal	Ade and Rehm (2020)
3	Encouraging circular waste economies for the New Zealand construction industry: opportunities and barriers	Journal	Low et al. (2020)
4	Refurbishment of office buildings in New Zealand: identifying priorities for reducing environmental impacts	Journal	Ghose et al. (2019)
5	Understanding construction stakeholders' experience and attitudes toward the use of structurally insulated panels (SIPs) in New Zealand	Journal	Harris et al. (2019)
6	Driving forces influencing the uptake of sustainable housing in New Zealand	Journal	Li et al. (2019)
7	Review of digital technologies to improve productivity of New Zealand construction industry	Journal	Chowdhury, Adafin and Wilkinson (2019)
8	Consequential LCA modelling of building refurbishment in New Zealand- an evaluation of resource and waste management scenarios	Journal	Ghose, Pizzol and McLaren (2017)
9	Structural insulated panels: a sustainable option for house construction in New Zealand?	Journal	McIntosh and Guthrie (2008)
10	Application of integrated GPS and GIS technology for reducing construction waste and improving construction efficiency	Journal	Li et al. (2005)
11	Prefabrication and waste minimisation in construction projects: perspectives from New Zealand	Conference	Luo and Shahzad (2020)
12	Lean Philosophy and BIM for productivity in New Zealand construction	Conference	Jerry, Babaeian and James (2020)
13	A critical review of the system-wide waste in the construction industry	Conference	Purushothaman and Seadon (2020)
14	Insights into the New Zealand prefabrication industry	Conference	Brown, Sharma and Kiroff (2020)
15	Optimising New Zealand construction consolidation centres: defining a research framework	Conference	Dhawan et al. (2020)
16	The New Zealand construction industry and sustainable construction through C&D waste minimisation: a review of the life cycle approach	Conference	Gade, Seadon and Poshdar (2020)
17	Potential for prefabrication to enhance the New Zealand construction industry	Conference	Moradibistouni and Gjerde (2017)
18	REBRI guides for waste reduction planning	Guide	Building Research Association New Zealand-BRANZ (2024)
19	Review of end-of-life options for structural timber buildings in New Zealand and Australia	Report	John and Buchanan (2013)
20	Waste not, want not	Magazine	Ross (2009)

1.4 The Current State of Residential Construction in New Zealand

The building and construction sector contributes significantly to New Zealand's economy, accounting for 6% of the total Gross Domestic Product (GDP) and employing approximately 11% of the total workforce (Ministry of Business Innovation & Employment-MBIE, 2023a). Residential construction has historically been the primary driver of national construction work in value, accounting for 56% of total construction activity in 2022, and is forecasted to maintain a dominant position in the coming years (Ministry of Business Innovation & Employment-MBIE, 2023b). The demand for new residential construction in New Zealand is primarily featured by population growth and GDP dynamics (Albsoul et al., 2023). The World Bank (2024) reported that 87% of the population in New Zealand lives in urban areas, with an annual population growth rate of 2.2%. Regions that have experienced significant urban expansion, namely Auckland, Canterbury, and Waikato, have the highest demand for residential construction, as indicated by the number of new consents issued for residential construction work between the years 2021 and 2024 (Stats NZ, 2021, 2024).

The growing population, coupled with urban expansion, can lead to future economic development and increased productivity (Di Clemente, Strano, & Batty, 2021). However, meeting the ongoing demand for new residential construction pressures material use and resource consumption. According to Marinova et al. (2020), the increasing global population and GDP are expected to accelerate the demand for raw materials, particularly in the residential construction sector, which accounts for up to 50% of global material consumption. Projections indicate that the global GDP will grow by an average of 2.8% until 2060, while using global primary materials is anticipated to rise by 1.5% annually (OECD, 2018).

The increasing demand for materials, driven by economic expansion and the need for residential construction, is causing a significant environmental crisis. The growing extraction and utilisation of materials contribute to a global increase in GHG emissions (Zhong et al., 2021). For instance, 90% of biodiversity loss is linked to resource extraction and processing operations (Gallego-Schmid et al., 2020). In addition, the disposal of material waste in landfills is leading to pollution of land, air, and water, posing a threat to the achievement of sustainable development goals (SDGs) and emission reduction targets, and exacerbating climate change (Kit, 2022; Ogunmakinde, Egbelakin, & Sher, 2022).

Furthermore, the New Zealand construction industry heavily relies on imported materials, with approximately 90% of products sourced from overseas (Ministry of Business Innovation & Employment-MBIE, 2023a). Over the past decade, the cost of construction materials surged by 22%

(Ministry of Business Innovation & Employment-MBIE, 2023a). The escalating volatility of material prices and the adverse financial and environmental effects of material waste have underscored the need to adopt circular economy principles and sustainable construction practices (Grafström & Aasma, 2021). Current strategies to address cost and environmental impacts include reducing waste, reusing materials and components, and implementing green building designs and innovative construction methods (Ghobadi & Sepasgozar, 2023; Udawatta et al., 2021).

The global construction landscape is evolving with the emergence of trends such as net-zero carbon buildings, regenerative design, and advanced technologies. These developments present an opportunity for the residential construction sector in New Zealand to elevate building performance, regulations, and quality standards. In line with this, New Zealand has committed to achieving net-zero carbon emissions by 2050 and has formulated a waste strategy focused on circular economy principles to reduce emissions and waste (Building Performance, 2023; Ministry for the Environment- MfE, 2023b). Waste reduction strategies are focused on enacting regulatory changes, infrastructure improvements, incentives, and a collaborative approach (Ministry for the Environment- MfE, 2023b). Furthermore, there is a growing emphasis on embracing emerging regenerative and passive building design methods, as well as exploring technologies like BIM, artificial intelligence (AI), and virtual reality (VR) to revolutionise the industry (Ministry of Business Innovation & Employment-MBIE, 2023a). Moreover, the construction sector is exploring the implementation of prefabrication and three-dimensional printing (3DP) to enhance efficiency and sustainability (Adafin et al., 2022).

In conclusion, the residential construction sector's impact on resource consumption, environmental considerations, and economic development underscores the need to transition to more sustainable building practices and waste reduction strategies. This transition can significantly influence New Zealand's progress towards achieving a sustainable built environment, circular economy, decarbonisation, and emission and waste reduction targets.

1.5 Decision-making in RCWR

Adopting sustainable practices in residential construction is crucial to encouraging CW reduction (Nasaruddin, Ramli, & Ravana, 2008). The construction industry often prioritises profitability over environmental concerns, which limits the efficiency of CW reduction (Viswalekshmi, Bendi, & Opoku, 2023). Besides, different stakeholders in the industry may have different or conflicting goals (Jaffar, Tharim, & Shuib, 2011). Menegaki and Damigos (2018) highlighted that communication among stakeholders is essential for efficient waste management. In addition, the knowledge of various stakeholders involved in the construction process about RCWR can promote and facilitate better implementation of waste management approaches (Munaro & Tavares, 2023). Numerous research studies have attempted to explore the role of stakeholders in CW management. However, existing literature primarily focuses on stakeholders' behaviour and willingness towards waste management, such as those of Umar et al. (2017) and Lu, Peng, et al. (2015). Furthermore, research investigations have emphasised reusing and recycling construction and demolition waste, for example, Kim, Nguyen and Luu (2020), without solely conceptualising RCWR.

As there are various groups of stakeholders participating in the decision-making for RCWR, different plans for CW management, a variety of design and construction methods applied, and the regulations differences among countries, achieving an optimal strategic decision for RCWR becomes a problem (Esa, Halog, & Rigamonti, 2017; Kabirifar et al., 2020). Besides, cost and time overruns and disputes are common in residential projects (Dlamini & Cumberlege, 2021; Megha & Rajiv, 2013), which may limit the efficient implementation of waste management practices (Ogunmakinde, Sher, & Maund, 2019).

Thus, decision-makers are often faced with trade-offs and uncertainty due to multiple factors influencing construction waste management (De Magalhães, Danilevicz, & Palazzo, 2019; Palafox-Alcantar, Hunt, & Rogers, 2020). According to Abbasianjahromi, Sepehri and Abbasi (2018), identifying the criteria for the decision-making framework is essential to be relevant and valid for the decision-maker. Several researchers have suggested approaches to developing strategies and planning in CW management depending on the focus of the assessment criteria. Studies focused on the environmental alternatives employ the life cycle assessment (LCA) approach. For example, Llatas et al. (2021) implemented LCA to evaluate environmental scenarios in Brazil's construction and demolition waste management systems, whereas Penteado and Rosado (2016) developed a framework to assess recycling strategies in CW management. Other studies employed the cost-benefit analysis approach to determine CW reduction economic gains and dynamics, such as Tu et al. (2023) and Stenis (2005).

The problems with these approaches are the limitations in criteria selection, the exclusivity of one group of decision-makers, and the lack of a structured approach. Therefore, applying multi-criteria decision-making (MCDM) is uniquely suited for the problem of optimising decision making in RCWR. MCDM facilitates the evaluation of multiple, often conflicting, criteria in a structured approach (Zavadskas & Turskis, 2011). Multiple decision-makers can evaluate an integrated set of criteria that capture the multifaceted factors in RCWR, facilitating more holistic and balanced decision-making.

MCDM methods are valuable tools for achieving the required balance between conflicted objectives. Previously introduced literature and industry and government reports indicate that, despite regulations, practices, and strategies, the effectiveness of decoupling CW from residential development remains inadequate. The application of MCDM optimisation and decision support tools in CW management is minimal and recent. There is also no evidence in the literature that MCDM has been explicitly applied in RCWR. Selecting the most suitable and optimal strategy for RCWR involves considering a wide range of factors. Thus, the primary aim of this research is to develop a decision-making framework for RCWR in New Zealand, which will streamline the decision-making process by identifying the most crucial criteria and optimal strategy.

1.6 Research Problem Statement

The residential construction sector in New Zealand plays a crucial role in both social and economic development, historically accounting for the largest proportion of total national work value. However, it has become increasingly scrutinised for contributing to the significant share of material waste in landfills and associated environmental impacts (Hossain & Ng, 2019). Thus, reducing CW is widely recognised as a fundamental step towards embracing circular economy principles and promoting overall sustainability in the built environment (Ogunmakinde, Egbelakin, & Sher, 2022).

The construction sector in New Zealand significantly relies on imported building materials and products, often facing logistics challenges and experiencing increasing costs and demand (Ministry of Business Innovation & Employment-MBIE, 2023a). A significant share of these materials is discarded in landfills due to inadequate sustainable practices. Therefore, meeting the rapidly growing demand for residential construction and the projected increase in waste generation requires a persistent need to optimise the performance of RCWR. In addition, the differences in logistics, supply chain, and building regulations create distinct challenges that differ from other countries (Jia et al., 2018; Melnyk, Narasimhan, & DeCampos, 2014).

As New Zealand strategically prioritises waste reduction to facilitate a transition to a circular economy, it is also reviewing the Building Act and remains committed to international agreements. This challenges decision-makers, who must balance sustainability with the increasing building demand while ensuring profitability. Such cases result in uneven decision-making due to the conflicting interests of various stakeholders. Consequently, enhancing the decision-making process at the government and business strategic levels was recommended to facilitate coordination and boost efficiency (Commerce Commission, 2022).

Waste reduction is defined as decreasing the value of produced waste through the effective use of selected factors (Aadal et al., 2013). While many factors influence CW reduction, refining influencing factors offers opportunities to rethink waste reduction strategies (Laovisutthichai, Lu, & Bao, 2022).

Moreover, understanding the influencing factors is valuable in providing stakeholders with a helpful set of criteria that improve decision-making in CW reduction (Wang, Li, & Tam, 2014). However, the presence of multiple stakeholders with diverse objectives and interests, along with numerous influencing factors, has complicated decision-making in waste management. This complexity emphasises the need for a structured approach in RCWR to determine the most optimal decisions that balance the various interests for effective strategy planning and resource allocation.

1.7 Research Scope

1.7.1 Waste type

Waste is typically generated during construction, demolition, or renovation activities associated with residential, commercial, or infrastructure projects (Liu, Yi, & Wang, 2020). This research explicitly examines solid waste in residential construction projects from the initiation to the completion. CW can be defined as the "physical waste" resulting from material losses at construction sites (Nagapan et al., 2012).

1.7.2 Geographical coverage

The focus of this research is on the Auckland region for several reasons. Firstly, the value of residential construction work in Auckland consistently exceeds the national level, with the highest number of approved new dwellings annually (Ministry of Business Innovation & Employment-MBIE, 2023b). The population in Auckland is projected to increase by 700,000, reaching 2.4 million by 2050, creating significant pressure on the residential construction sector to meet this demand (Auckland Council, 2024a). Auckland represents 43% of consented residential units in 2022, with a goal of building more than 400,000 homes over the next 30 years to accommodate this growth (Ministry of Business Innovation & Employment-MBIE, 2023b; Real Estate Institute New Zealand- REINZ, 2022). Addressing built environment issues, Auckland Council (2024a) highlighted CW as a major challenge, constituting up to 50% of Auckland's total waste. Additionally, climate action is a top priority for the Auckland Council, with a strong emphasis on reducing CW as part of Auckland's climate plan (Auckland Council, 2020a).

1.7.3 Unit of analysis

This research requires multiple units of analysis, such as conducting systematic reviews of existing literature and engaging with individuals and groups of relevant stakeholders connected to the research topic. Relevant stakeholders are identified and categorised based on the reviewed literature. Additionally, the semi-structured interviews, questionnaire, focus group workshop, and validation exercise for this study’s developed multi-criteria decision-making (MCDM) framework focuses on engaging the identified stakeholders as the unit of analysis.

1.8 Research Aim

The goal of this research is to develop a performance-based framework to optimise decision-making in RCWR in New Zealand. To achieve the research aim, four key objectives have been proposed, and five research questions have been formulated to be answered.

1.8.1 Objective 1: To articulate the fundamentals of RCWR

This objective explores the fundamentals of RCWR. Understanding the concepts of RCWR requires a comprehensive literature review to identify the barriers, benefits, and current trends in sustainable practices necessary to enhance RCWR. Additionally, it is essential to outline the key stakeholders who can impact RCWR optimisation, as well as their level of involvement and contribution to improving decision-making. Therefore, two research questions (RQs) need to be addressed to achieve this objective:

RQ1: What are the concepts of RCWR?

RQ2: Who are the key stakeholders of RCWR?

1.8.2 Objective 2: To investigate factors influencing RCWR in New Zealand

This objective is essential for exploring stakeholder views about the factors influencing RCWR in New Zealand. It emphasises the significance of RCWR and underscores the priority areas for decision-making. The proposed research question for achieving this objective and gaining a deeper understanding of RCWR is as follows:

RQ3: What factors influence RCWR in New Zealand?

1.8.3 Objective 3: To evaluate the importance of factors influencing RCWR

This objective aims to evaluate and verify all the factors collected from the literature and interviews essential to optimising RCWR in New Zealand. The significance of each factor will be examined by employing structural equation modelling (SEM). The developed model reveals the influence and relationships of influencing factors. To achieve this objective, the following research question is proposed:

RQ4: How important are the factors influencing RCWR?

1.8.4 Objective 4: To develop and validate the RCWR framework

After identifying and verifying the influencing factors, a decision-making framework will be developed to optimise the criteria selection for strategy development in New Zealand through a focus group workshop. The framework ranks and rates the criteria based on the level of importance. Therefore, the following research question is anticipated to be answered:

RQ5: How can a decision-making framework for RCWR in New Zealand be developed and validated?

1.9 Research Design

1.9.1 Research paradigm and philosophical position

Ontology, epistemology, methodology, and methods are the fundamentals of any research paradigm (Zukauskas, Vveinhardt, & Andriukaitienė, 2018); see Table 1.2. Ontology is the philosophy concerned with describing the existing knowledge of the research object (Slevitch, 2011). Thus, ontology establishes the research's philosophical position and starting point. Epistemology is the philosophy concerned with the means and objectives of knowledge. According to Zukauskas, Vveinhardt and Andriukaitienė (2018), the research paradigm combines the nature and knowledge (ontology) of research and the perceived research assumption (epistemology). The methodology is the interface between ontology and epistemology, which comprises the tools and steps to develop new knowledge (Zukauskas, Vveinhardt, & Andriukaitienė, 2018).

Table 1.2: The fundamentals of the research paradigm (Zukauskas, Vveinhardt, & Andriukaitienė, 2018)

Fundamentals of research paradigm	**Definition**
Ontology	Understanding 'What' knowledge is available about the entity of research
Epistemology	Investigate the means to understand the ontology of research and the 'How' to investigate it.
Methodology	The general collective approach and methods of tools and techniques that researchers use to collect and analyse data.

The different combination of these fundamentals distinguishes different research philosophies. Construction management research suggests two research philosophies: the positivist and the interpretivist (Love, Holt, & Li, 2002; Seymour & Rooke, 1998); refer to Table 1.3. Interpretivism research philosophy interprets the research objective in a subjective manner (Zukauskas, Vveinhardt, & Andriukaitienė, 2018). The basis of the interpretivism research philosophy is understanding how people experience the research objective. According to interpretivism, the researcher's interests are the basis of the research's objective. On the contrary, the positivist research philosophy is an approach that involves collecting empirical research evidence objectively (Zukauskas, Vveinhardt, & Andriukaitienė, 2018). In positivist research, the researcher interacts with actual practice and knowledge is analysed objectively (Zukauskas, Vveinhardt, & Andriukaitienė, 2018).

Table 1.3: Research paradigms concerning Epistemology, Ontology, and Research methods (Zukauskas, Vveinhardt, & Andriukaitienė, 2018)

Research Philosophy	Ontology	Epistemology	Research methods
Interpretivism (Qualitative)	The reality is subjective	Knowledge is based on the abstract descriptions of meanings, constructed of social experiences and multiple perspectives (constructivism)	Case studies Interviews
Positivism (Quantitative)	The reality is objective	Knowledge is fundamental and can be measured (reductionism)	Survey, experiment, quasi-experiment

Research in construction management is not restricted to a particular research philosophy due to the nature of construction projects, the researcher's understanding of the problem, and the level of the developed theory. However, Love, Holt and Li (2002) reviewed triangulation in construction management. They suggested using mixed methodologies as an optimal research philosophy to establish how to tackle deeply rooted problems using a holistic approach. The study explained that construction projects are known for their complex and dynamic nature, comprising different components with multiple interactions and relationships (Love, Holt, & Li, 2002). Additionally, construction projects are human endeavours that are impossible to study using exclusively scientific methods about managerial concerns between any of the project's components. Hence, the sole use of positivism for theory development in construction management is hindered by the nature of the actors leading construction projects, which are 'People'.

1.9.2 Mixed-methods research design

This research incorporates mixed data collection and analysis methods as a research strategy. Mixed methods research allows qualitative and quantitative data to overcome significant but complex problems (Ivankova & Wingo, 2018). The research mainly follows the exploratory sequential mixed-methods design. In this design, the quantitative phase is embedded in the views explored by participants in the qualitative phase (Dawadi, Shrestha, & Giri, 2021). The research design is illustrated in Figure 1.2.

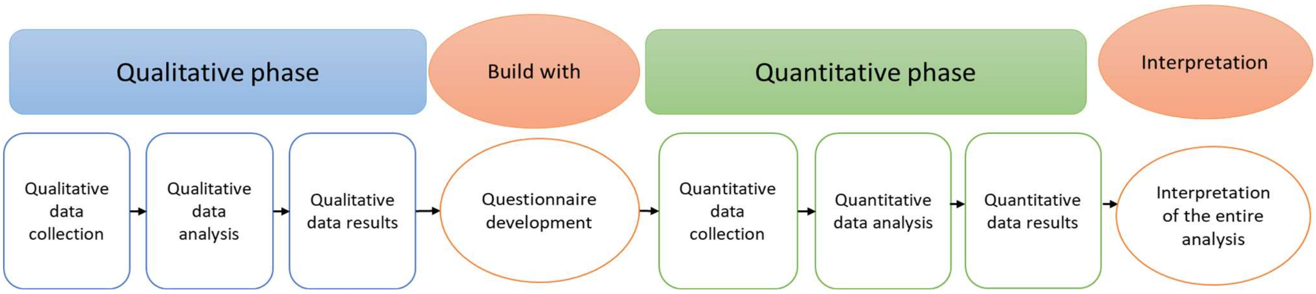

Figure 1.2: Sequential exploratory mixed-methods design (Creswell, 2017)

Selection for mixed methods provides a more profound and extensive meaning of integrated data (Creswell, 2017). The qualitative method is beneficial for pointing out critical issues and providing richness and profound observation of the researched data (Dworkin, 2012; Henry et al., 2015; Kelle, 2006), which helps hypothesise and interpret the complexities of quantitative findings (Henry et al., 2015). Besides, the quantitative approach is valuable for testing hypotheses and identifying the examined variables clearly and definitively (Almalki, 2016; Matveev, 2002).

The focus of this research is on the factors influencing CW reduction in New Zealand's residential construction sector, along with an emphasis on the interrelationship among influencing factors to guide decision-making and design strategies to enable RCWR. The literature review was the initial step in the qualitative phase, which revealed the concepts related to RCWR and identified the key stakeholders involved. The findings from the literature were then used to develop interview questions aimed at exploring key stakeholders' views on the factors influencing RCWR in New Zealand. Once the data from participants was obtained and analysed, it was used to construct questionnaire items. The purpose of conducting the questionnaire is to bridge qualitative and quantitative data. The quantitative data collected are valuable in assessing and understanding RCWR influencing factors. The overall research methodology steps are illustrated in Figure 1.3.

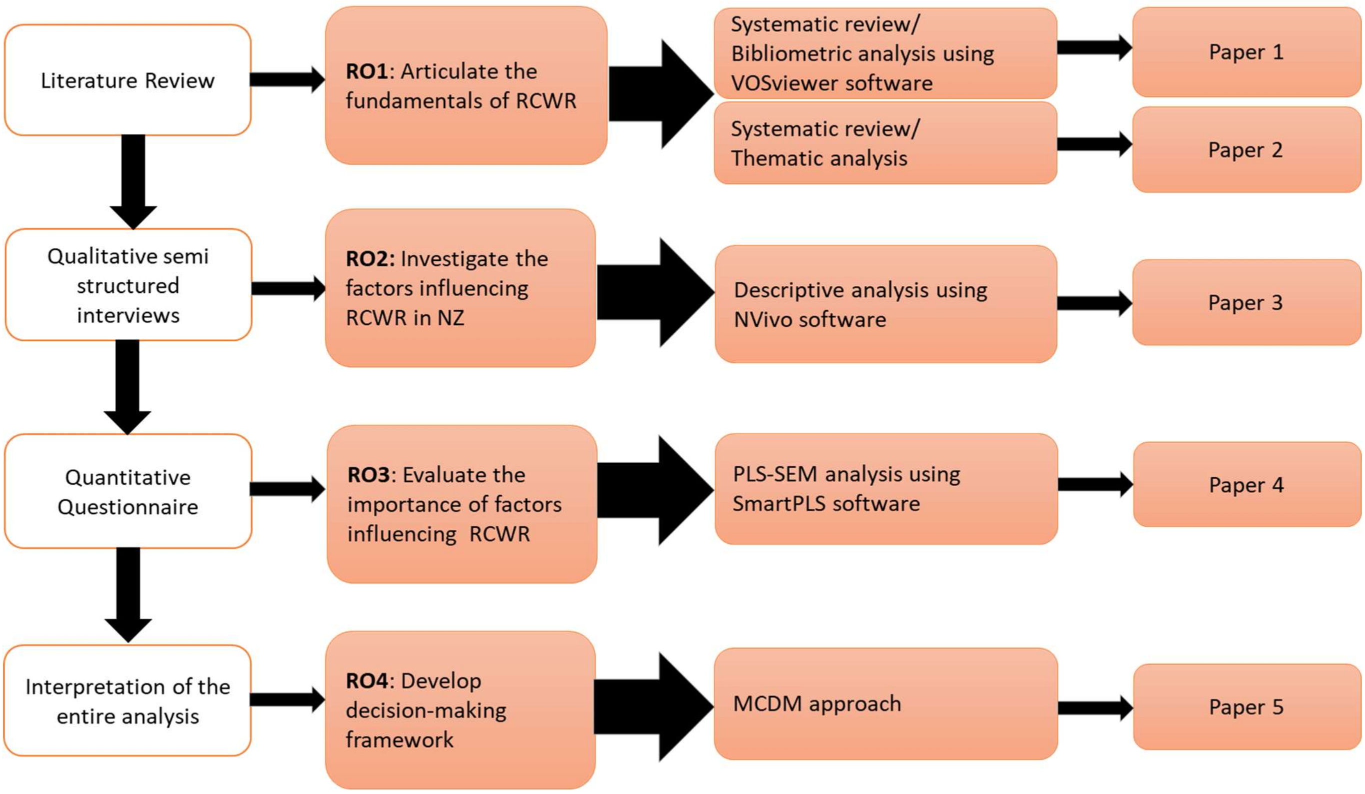

Figure 1.3: Overall research methodology design

1.10 Data Collection Methods

Four data collection instruments were employed for the entire data collection process to achieve the research aim (See Figure 1.3). These data collection instruments are described as follows.

1.10.1 Systematic literature review

The ontology (nature) of RCWR practice in terms of what RCWR 'is', what it aims to 'do', and whom the actors leading RCWR must be, is the starting point of all theoretical activity in this research. Therefore, **RO1** seeks to articulate the fundamentals of RCWR in understanding the concepts of RCWR and identifying the key stakeholders. To achieve **RO1**, a systematic literature review was conducted using two approaches: a bibliometric and critical review for **RQ1** and Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) for **RQ2**.

Bibliometric analysis is a quantitative systematic literature review that follows a consistent, comprehensive, and evident-based approach to retrieve, systematise, and statistically analyse data (Norouzi et al., 2021). Bibliometrics ensure the reliability and robustness of quality and quantity measures, which are valuable in comparing concepts (Castillo-Vergara, Alvarez-Marin, & Placencio-Hidalgo, 2018). A fundamental characteristic of this technique is generating a visual map of bibliometrics to envision the emergence of a specific research topic and its gradual structural development. Additionally, bibliometric maps are valuable for understanding the trending research themes and recent research interests over time (Linnenluecke, Marrone, & Singh, 2020).

Successful RCWR requires the involvement and participation of all stakeholders. Such stakeholders must be identified, and their roles must be clearly understood to understand their influence on decision-making. The contributions and interactions of stakeholders to RCWR practices provide valuable insights into involved stakeholders' roles and decision dynamics to implement and coordinate RCWR successfully. According to Terry et al. (2017), thematic analysis is a flexible qualitative tool that aims to generate a patterned set of meaningful data (referred to as themes) that acknowledge research questions. Patterns are developed following a thorough process to create codes, develop themes, and validate results (Terry et al., 2017).

1.10.2 Semi-structured interviews

Conducting in-depth interviews was the starting point of the qualitative phase of this research. **RO2** seeks to identify influencing factors that can significantly impact the effectiveness of RCWR in New Zealand. To gain a holistic view, factors influencing RCWR were collected from subject matter experts who are key stakeholders in RCWR using the qualitative design method of semi-structured interviews. The collected data were the primary source of empirical data in this research. In-depth interviewing explores the views and perspectives on a concept or a state of interest by organising thorough interviews with a sufficient number of respondents individually (Johnson & Rowlands, 2012). The interviews followed a semi-structured design that required pre-determined questions. The questions were designed based on pre-identified themes from **RO1** that allow interposition to pursue more clarifications (Qu & Dumay, 2011).

According to Adeoye-Olatunde and Olenik (2021), the conversation begins with a focus on a particular area and continues to develop as more questions emerge. Then, the themes will be identified from the reviewed literature, and research questions will be formed. Including a literature review is also necessary for this step. Literature provides as much information and knowledge in RCWR as possible, in which relevant themes and interview questions will be formulated. Interviewees are the key stakeholders influencing RCWR decision-making in New Zealand who were identified in **RO1**. Therefore, expertise was a crucial requirement for participant selection in the interviews. A minimum of 3 years of experience in New Zealand's residential construction sector was required to ensure relevant and reliable qualitative data.

1.10.3 Questionnaire survey

The influencing factors were identified and defined in the qualitative phase after achieving **RO1** and **RO2**. A survey questionnaire was constructed to obtain research data, including constructs and indicators for the model for the quantitative phase to achieve **RO3**. The identified model variables were evaluated and verified using the structural equation modelling (SEM) method. The questionnaire aimed to evaluate the importance of factors and provided insights into their interrelationships. The collected data were quantitatively measured, analysed, and validated through partial least squares-structural equation modelling (PLS-SEM) method. Therefore, the questionnaire design reflected this purpose. The nature of the questionnaire was cross-sectional to enable the collection of data at one point in time (Creswell, 2017).

The questionnaire design and data collection were internet-based. Internet-based questionnaires are considerably efficient and effective in terms of time, cost, and effort and are valuable in constructing the questionnaire and collecting, storing, and visualising the data (Nayak & Narayan, 2019). Another advantage is that online survey tools accelerate data analysis due to easier data processing (input and verification) and managing forms (Cooper et al., 2006).

Qualtrics was the selected software tool for questionnaire design and data collection. Molnar (2019) revealed some advantages of Qualtrics, including (i) the ability to customise an intuitive survey; (ii) could be integrated with other tools for analysing data, eliminating bias, and data presentation; and

(iii) being supported by multiple operating systems either web or phone-based for more straightforward user experience. In addition to these advantages, AUT supports the Qualtrics license. Once the questionnaire design was ready, it was posted on LinkedIn's professional network, and in-person workshops, conferences, and networking events were attended to distribute the research questionnaire poster. In addition, participants were invited to share the questionnaire link and research poster through their network.

1.10.4 Focus group workshop

A focus group workshop was the technique selected for data collection and validation for the practicality of the developed framework in New Zealand. A prominent feature of the focus group technique is providing an opportunity to generate ideas and understand the conflict of interests of all participants, which helps improve the criteria performance (Aigwi et al., 2022). The focus group technique has been frequently applied in literature for data collection and validation (Aigwi et al., 2022; Pidgeon & Dawood, 2021). The primary step involved clearly setting the focus group's objective and purposefully selecting participants.

Accordingly, conducting a focus group workshop aimed to understand RCWR factors in-depth and assess the integration of stakeholders' priorities and interests. The stakeholders were decision-makers in RCWR and were purposefully selected based on their relative experience with RCWR. Logistics planning, such as venue, materials and types of equipment, was considered at this step. The following steps were applied to the multiple criteria decision-making (MCDM) data collection (weighting and scoring) and analysis (ranking) techniques. The final step was aggregating results and reporting.

The MCDM weighting and scoring data collection technique is a formalised process for providing systematic and transparent outcomes during focus group decision-making processes (Kandakoglu, Frini, & Ben Amor, 2019). For **RO4**, the combined Fuzzy Technique for Order Preference by Similarities to the Ideal Solution (TOPSIS) and Fuzzy Decision-Making Trial and Evaluation Laboratory (DEMATEL) MCDM weighting and scoring methods were employed to validate the performance-based framework because of the complex multi-criteria nature of the RCWR decision-making process. Accordingly, a focus group workshop was conducted with relevant decision-makers to administer the MCDM performance-based methodology while exploring and balancing their opinions as a group.

1.11 Research Contribution

This research contributes to practical and theoretical knowledge through conceptualised findings in CW reduction, construction management, sustainable residential construction, circular economy, and performance-based decision-making frameworks. The research contributed to advancing knowledge gaps about RCWR in New Zealand. The empirical findings determined the indicators influencing performance for RCWR decisions. In addition, prioritising the importance level and influence of each criterion of indicators assisted in developing effective RCWR decision-making. Moreover, the findings from this thesis enrich the theoretical body of knowledge and provide a valuable reference point for researchers exploring related topics.

In practice, this research proposed a framework aimed at effectively optimising the performance of RCWR. This framework was designed to assist decision-makers in prioritising and developing strategies, thus enabling resource allocation via a balanced interest set of criteria. The developed performance-based RCWR framework has successfully served as a guide for industry and government experts in New Zealand, aiding them in planning, developing strategies, and prioritising indicators to optimise RCWR while balancing the diverse interests of all decision-makers. This framework is also applicable to other countries with indicators like those of New Zealand.

This research establishes the importance of RCWR in New Zealand and countries with shared commitment and challenges worldwide for fostering collaborations among stakeholders and facilitating the transition toward a circular economy and sustainable construction. Addressing sustainability challenges in the residential construction sector is consistent with achieving the United Nations-UN (2015) SDGs. As such, decisions aimed at optimising RCWR contribute to the attainment of SDG13 (climate action) and the advancement of SDG12 (responsible consumption and production). Furthermore, adopting innovative technologies in residential design and construction supports SDG9 (industry, innovation, and infrastructure) while promoting SDG11, “make cities inclusive, safe, resilient and sustainable" by decoupling urbanisation expansion and the impacts of RCWR. This research presents valuable references for future studies by providing insight into the current RCWR status in New Zealand. In conclusion, a summary of the research aim, objectives, research questions and contributions of the research is illustrated in Figure 1.4.

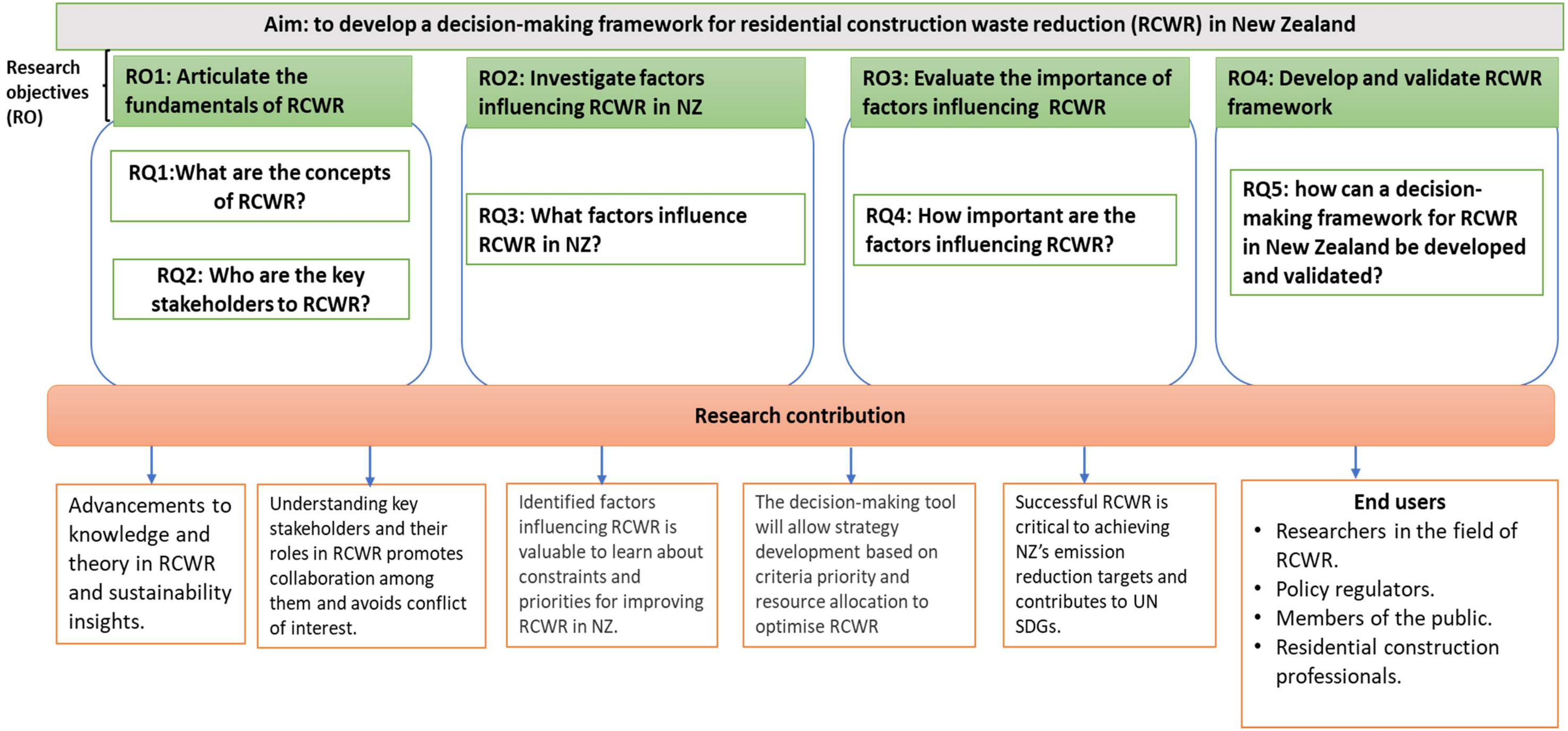

Figure 1.4: Research aim, questions, objectives, and contributions

1.12 Thesis Structure

This PhD thesis is organised into seven chapters as follows:

Chapter One provides an overview of the research, outlining the characteristics of the residential construction industry in New Zealand, as well as background information on CW reduction and the significance of decision-making in RCWR. Following this, the problem statement is presented to justify the need for conducting this research, along with the research scope, aim, objectives, and contributions. Subsequently, the methodological design and the philosophical stance are explained.

Chapter Two delivers a comprehensive review of the current studies in RCWR by employing a systematic literature review and discusses how this research contributes to state-of-the-art knowledge. The trends in sustainable RCWR practices, the barriers and benefits to RCWR, and the future direction in RCWR for New Zealand.

Chapter Three explores the current studies on categorising stakeholders in RCWR. It analyses and conceptualises the interactions and contributions of RCWR stakeholders and discusses strategies to enhance stakeholder collaboration and contribution to RCWR.

Chapter Four investigates the factors influencing RCWR in New Zealand, conducting interviews with relevant stakeholders. The findings from chapters one and two were used to design the themed questions for the semi-structured interviews and the sampling of experts based on the influence of the stakeholders relevant to RCWR. The factors were categorised into eight groups, and priority areas for strategy development were highlighted.

Chapter Five examines the findings of Chapter Four using a questionnaire survey and structural equation modelling (SEM). The hypothesised structural relationships between the factors are evaluated, and the developed structural and measurement models are assessed. The findings are used to develop the criteria of the decision-making framework.

Chapter Six proposes the multi-criteria decision-making (MCDM) framework by ranking and rating the criteria based on their importance. The framework is then proposed to facilitate strategy development, prioritise resource allocation, and ultimately enhance RCWR's performance.

Chapter Seven concludes the research findings by integrating them with the research objectives. It then follows with recommendations for future research and highlights of research limitations.

Chapter 2: A Review of Extant Literature and Recent Trends in Residential Construction Waste Reduction

2.1 Prelude

The residential construction sector in New Zealand and worldwide is experiencing increased criticism for generating substantial waste that poses environmental concerns. Accordingly, researchers have advocated implementing residential construction waste reduction (RCWR) strategies as a sustainable solution to managing construction waste (CW). This article aims to provide a comprehensive overview of RCWR by analysing 87 articles from the Scopus database using bibliometric and critical review methods. The co-occurrence analysis of keywords revealed five clusters, in which five main themes emerged: (i) waste generation and management performance, (ii) prefabrication and life cycle assessment concepts, (iii) design concepts, (iv) circular economy and (v) decision-making concepts. The findings suggest that sustainable practices such as designing for waste reduction, prefabrication, waste quantification, three-dimensional printing and building information modelling can effectively achieve RCWR. The study also highlights the benefits of RCWR, including reducing environmental impacts, and identifies management, economic, legislative, technology and cultural barriers that affect the implementation of RCWR strategies. These results provide valuable insights to support future policy formulation and research direction for RCWR in New Zealand.

2.2 Introduction

Residential construction has a fundamental role in boosting employment, economy and social development (Arestis & González-Martínez, 2015; D. Li et al., 2013), contributing significantly to natural resources and material consumption worldwide (Hossain & Poon, 2018). The volume of materials used for constructing new residential dwellings in New Zealand has more than doubled in the past 30 years, from around 820,000 tonnes to over 2 million tonnes (Nelson et al., 2022). Along with material consumption, construction activities generate vast amounts of waste (Wuyts et al., 2019). Past research suggests that CW forms around 35% of the global solid waste (Liu, Yi, & Wang, 2020).

Material use consumption is unevenly distributed worldwide and is closely linked with rapid urbanisation and population growth. The forecasted trend of urbanisation and population growth in developing economies until 2050 is expected to increase demand for residential construction and material consumption (Aslam, Huang, & Cui, 2020; Marinova et al., 2020; Zhong et al., 2021). According to the Building Research Association of New Zealand (2020), CW accounted for half of the total waste sent to landfills in New Zealand, totalling over 3.6 million tonnes annually. Notably, the residential construction sector played a significant role, contributing 60% of the total construction value in 2020 (Ministry of Business Innovation and Employment-MBIE, 2021). The volume of residential CW in New Zealand was estimated at 347 thousand tonnes in 2021, with 267 thousand tonnes ending in landfills (Nelson et al., 2022). Consequently, addressing this challenge remains an ongoing concern for the construction industry and the sustainability efforts in the built environment.

Moreover, the existing linear economic model exacerbates induced pressure on natural resources due to the excessive demand for extracting raw materials on one end and excessive waste disposal on the other end, exceeding the capacity of ecosystems (Ghaffar, Burman, & Braimah, 2020). Global policies acknowledge the urgent need for the construction industry to reduce material waste and the depletion of resources. For instance, China increased scrutiny over implementing effective CW reduction practices through housing development projects' design and construction phases (Li et al., 2022). In addition, the United Kingdom strengthened compliance controls on implementing the waste management law and constantly increased landfill tax and CW disposal costs (Osmani, 2012). Furthermore, the European Commission (2022) enacted the 'waste framework directive' in 2008, citing CW reduction as one of the main objectives for achieving a circular economy and resource efficiency in Europe.

Likewise, 'Waste reduction' is the prime focus of the New Zealand government's quest to transition into a circular economy and emission reduction target (Ministry for the Environment- MfE, 2021a). As a result, the New Zealand government has expanded the scope of the landfill levy to include landfills that receive CW (Ministry for the Environment- MfE, 2021c). These measures prioritise adopting a circular economy approach to promote the sustainable utilisation of construction materials. The circular economy model aims to maintain the continuous flow of products and materials, diminishing the reliance on new materials and reducing detrimental environmental effects (Stephan & Athanassiadis, 2018).

Although policy and regulatory changes have been implemented to promote and improve CW reduction, the limited progress raises significant concerns. As a result, researchers are increasingly dedicating their efforts to enhancing the knowledge and practices of CW reduction. Several studies have focused on CW reduction, albeit with different emphases. De Magalhães, Danilevicz and Saurin (2017) studied CW reduction in infrastructure projects, whereas Osmani, Glass and Price (2008), Ding et al. (2018), Wang, Li and Tam (2015), and Banihashemi, Tabadkani and Hosseini (2018) focused on improving CW reduction during the design stage of construction projects. Some studies have found that conventional construction methods and practices are hindering the successful reduction of CW (Abarca-Guerrero, Maas, & Van Twillert, 2017). However, to promote collaborative efforts and encourage the involvement of stakeholders towards implementing sustainable waste management practices (Chammas et al., 2020; Nasaruddin, Ramli, & Ravana, 2008), there needs to be a better understanding of the benefits and barriers to reducing CW in New Zealand.

Numerous studies have already contributed novel insights to research concerning CW in residential construction in New Zealand; for example, Domingo and Batty (2021). However, there is a shortage of comprehensive reviews focusing explicitly on residential construction. Furthermore, the current body of literature has not systemised the concepts of residential CW, impeding the formulation of effective strategies. Additionally, there is a lack of contemporary insights into emerging methodologies and the prospective benefits and barriers to implementing CW reduction strategies in the residential construction sector in New Zealand, necessitating the urgency to address this knowledge gap. This research, therefore, aims to conduct a comprehensive and systematic review of existing research in the field of residential CW reduction. Accordingly, utilising the term "residential construction waste reduction" (RCWR) reflects the primary focus of this review. The research objective is to explore the concepts of RCWR by addressing the following research questions:

RQ1: What is the state of the art in RCWR?
RQ2: What are the sustainable practices of RCWR?
RQ3: What barriers and benefits should be considered in implementing RCWR in New Zealand?
RQ4: What insights can New Zealand acquire for future direction?

The findings from this article are expected to yield valuable information for policymakers to formulate future RCWR and shift towards a circular economy. Embracing construction practices in a circular economy model will enhance New Zealand's competitiveness by shielding businesses from material shortages and price volatility. Consequently, the shift to a circular economy stimulates the development of innovative business opportunities and more efficient residential construction approaches. The benefits and barriers of implementing RCWR practices contribute to prioritising circular economy policies. Moreover, the review findings would provide researchers with deeper insights into RCWR.

2.3 Methodology

This article combines bibliometric and critical review analysis methods to provide a comprehensive systematic review of existing literature. The method comprises three core steps: collecting prior studies, analysing the data and conveying the results. These steps were modelled and adjusted from the methodologies proposed by Nazari et al. (2021) and Pizzi et al. (2020). The methodology flow is illustrated in Figure 2.1.

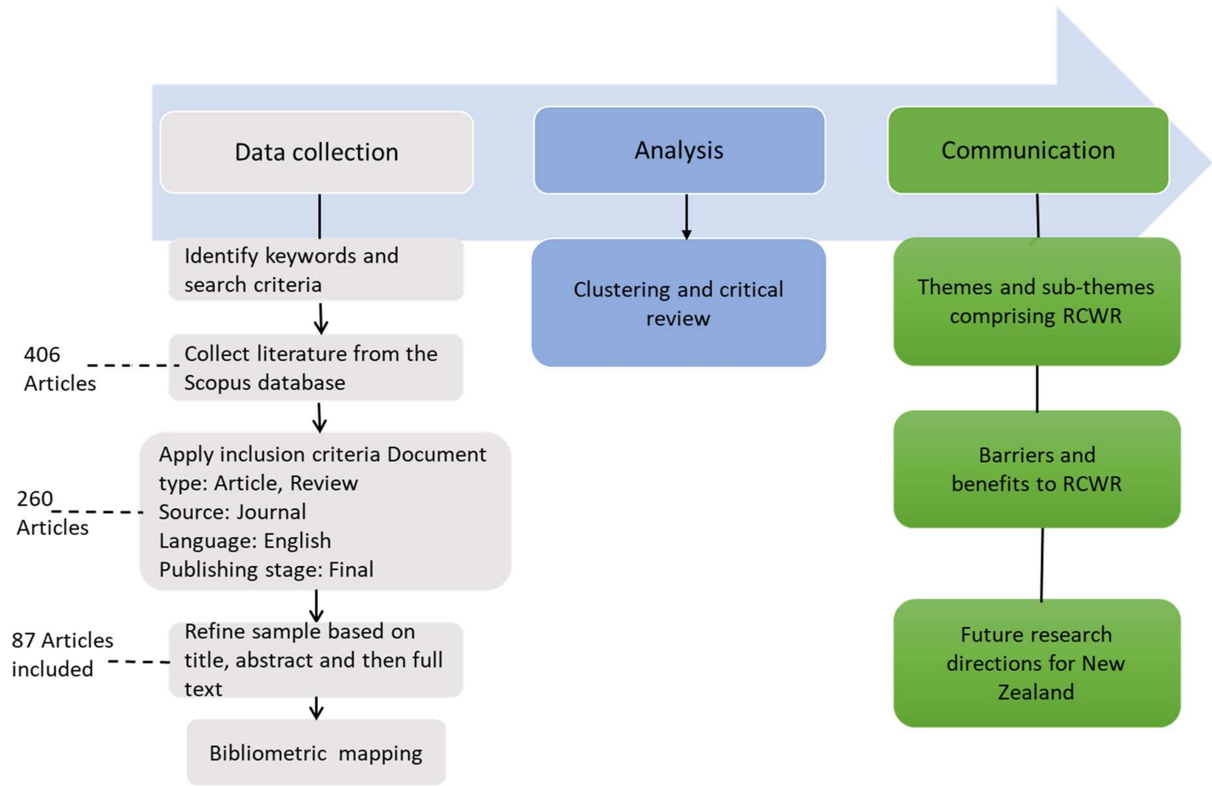

Figure 2.1: Methodology flow

2.3.1 Data collection

The data collection process follows a systematic search strategy restricted to the Scopus database through identified keywords and inclusion criteria. Elsevier Co. developed the Scopus database, which offers abstract reading and access to full-text documents (Burnham, 2006; Schotten et al., 2017). The main features of the Scopus database are extensive document coverage and quality. Scopus is the only database with large-scale peer-reviewed articles in all disciplines (Schotten et al., 2017). Compared to other databases, Scopus has the most coverage for recent and peer-reviewed articles (Chadegani et al., 2013). Peer-reviewed articles establish the credibility of research findings and reduce bias (Soderberg et al., 2021). Furthermore, Scopus supports using bibliometric tools over collected data (Sweileh, 2018).

Keyword search is the most critical step in bibliometric analysis because of the significant impact on the study results. Generally, identifying the search criteria requires (i) using generic literal concepts (e.g. 'construction waste'), (ii) using Boolean operators to narrow or broaden the research area (e.g. AND, OR), (iii) using the Truncation technique using symbols such as: *, (e.g. waste minimi* = waste minimisation, waste minimisation). This article used all the options mentioned. Using a comprehensive set of keywords, we aim to ensure that our literature review covers various relevant publications. This approach helps us capture a more holistic view of the research landscape on the chosen topic, ensuring the inclusion of all significant studies and allowing for a more thorough analysis of the research domain.

Initially, a basic search with general keywords was performed on Scopus as follows: (‘construction waste reduc*’ AND ‘residential’). Only nine documents were retrieved. A fundamental literature review was conducted to find related generic literal terms to extract the maximum number of articles available in the RCWR area. Firstly, although this research focuses only on CW, literature tends to group the waste products from demolition and construction activities together (Park & Tucker, 2017). Hence, the term ‘construction and demolition waste’ will be used. Moreover, the publication related to waste reduction would alternatively use a different expression to refer to its fundamental concepts in their work aspect. For example, Ajayi et al. (2014) mentioned that waste reduction is a strategy in CW management that minimises waste at the source.

Waste reduction is the optimal approach in the waste hierarchy following the 3Rs principle (reduce, reuse, recycle) (Kabirifar et al., 2020). Some literature mentioned prevention strategies as powerful tools in CW reduction or minimisation (Esin & Cosgun, 2007; Laovisutthichai, Lu, & Bao, 2022). Moreover, Umar et al. (2017) revealed that CW reduction could be achieved through the ‘zero waste’ principle. Other literature highlighted waste reduction as one of the objectives of the ‘circular economy’ (OECD, 2020).

In addition, keywords such as: ‘sustainable construction’ and ‘sustainable built environment’ have been increasingly regarded for promoting sustainable waste management practices, including waste reduction (Dahiru, Abdulazeez, & Abubakar, 2012; Del Río Merino, Izquierdo Gracia, & Weis Azevedo, 2010). Hence, the final keywords combination applied for the search criteria is: (((‘Construction waste’ OR ‘construction waste management’ OR ‘construction waste minimi*’ OR ‘waste prevent*’ OR ‘source reduc’ OR ‘construction and demolition waste’ OR ‘construction and demolition waste management’ OR ‘waste reduc*’ OR ‘material* waste’ OR ‘waste minimi*’ OR ‘3Rs principle’ OR ‘zero waste’ OR ‘reduc* waste’) OR (‘sustainable built environment’ OR ‘circular economy’ OR ‘sustainable construction’) AND (‘residential build*’ OR ‘hous* construction’ OR ‘residential construction’ OR ‘residential project*’ OR ‘residential build* construction’))).

The keywords-based search in Scopus returned 406 related publications. An initial filter criterion was created with limitations to include only fully published articles, document type of review and article and document source of journals. Journal articles and reviews are peer-reviewed, achieving the objectives of systematic reviews in reducing bias and improving data quality (Paez, 2017). Moreover, only publications in the English language are selected because it is the spoken language in New

Zealand and the most dominant in the international scientific literature (Rao, 2019). After applying the initial filter criterion, 260 articles were retrieved. Regarding the search period, the search concluded in March 2022. Therefore, only articles published up to March 2022 were included in the review.

Further reading to the title and abstract, then the full text to refine the resulting articles based on the research objectives, 87 articles were included. Only articles focused on residential construction and related waste reduction were included. Articles related to the waste reduction of demolition or renovation in residential construction projects were excluded. For example, Sobotka, Sagan and Radziejowska (2019), Cha, Kim and Kim (2012), and C. Zhang et al. (2021). The distribution of the annually published articles included in the review is shown in Figure 2.2.

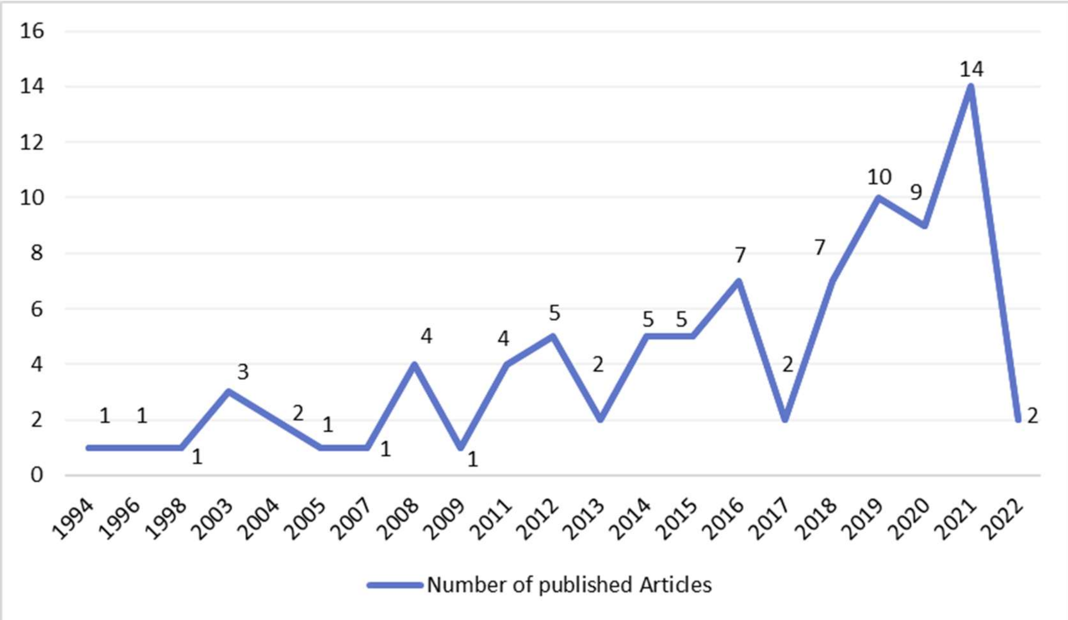

Figure 2.2: The number of published articles included per year

2.3.2 Bibliometric mapping

Bibliometric mapping is a quantitative systematic literature review that follows a consistent, comprehensive and evidence-based approach to retrieve, systematise and statistically analyse data (Norouzi et al., 2021). Bibliometrics offers quality and quantity indicators that are valuable in ranking and comparing concepts robustly and reliably (Castillo-Vergara, Alvarez-Marin, & Placencio-Hidalgo, 2018). A fundamental characteristic of this technique is generating a visual map of bibliometrics to envision the emergence of a specific research topic and its gradual structural development. Additionally, bibliometric maps are valuable for understanding the trending research themes and recent research interests over time (Linnenluecke, Marrone, & Singh, 2020). In this article, the selected bibliometric mapping is the keyword mapping based on the co-occurrence of keywords.

The keywords co-occurrence map is a valuable tool that effectively supports data mining and illustrates the main topics within the selected research area (Wang, Xu, & Škare, 2020). The visual mapping of keywords and their relationship displays the knowledge and order rationale of research themes (Jin, Yuan, & Chen, 2019). To create the keywords co-occurrence map, the unit of analysis is set to the 'all keywords' and 'full counting' method. A minimum of three is set for the occurrence of the keyword. Of the 909 keywords, 108 met the threshold. For each of the 108 keywords, the total strength of co-occurrence links with other keywords is calculated by VOSviewer. The keywords with the greatest total link strength selected are 108.

The next step is data cleaning to verify selected keywords, remove duplicates, and provide a more understandable and defined keyword analysis. Hence, general terms such as 'construction', 'demolition' and 'waste' were removed. Keywords with similar idiomatic expressions, for example, 'construction materials' versus 'building material', 'residential building' versus 'residential buildings' versus 'residential construction', were included in a subsequent round. As a result, 37 keywords in total were included.

2.4 Analysis

2.4.1 Cluster analysis and critical review

The included keywords are visualised and clustered in Figure 2.3 based on the number of keyword occurrences using the VOSviewer. The keywords cluster map shows state-of-the-art advancement in RCWR. Furthermore, it helps to find how different subfields are interconnected and find the potential opportunities for bridging the gaps between subfields.

This article proposes using combined methods of cluster analysis and critical review to give an in-depth analysis of the RCWR review. Cluster analysis is a technique for statistical data analysis and knowledge discovery used to identify the semantic themes hidden in the textual data (Daud et al., 2010). The keywords are clustered by the correlation among terms, simplifying the formulation of themes (X. Li et al., 2018). Additionally, the generated theme of each cluster is based on the keywords of the articles cited in the cluster and represents the cluster's focus. However, some critical articles could be overlooked because of the small number of related keywords. Therefore, a critical review was conducted to eliminate subjective interpretation, gain reliable knowledge and overcome the limitations of co-occurrence analysis in answering the research questions.

Based on the cluster analysis results in Figure 2.3, several clusters highlight the keywords of fields of study focused on RCWR. The keywords in RCWR can be classified into five themes as follows: cluster 1: waste generation and management performance; cluster 2: prefabrication and LCA concepts in

RCWR; cluster 3: design concepts in RCWR; cluster 4: recycling and circular economy and cluster 5: decision-making concepts in RCWR. Subsequently, these clusters are discussed to construct a holistic view of RCWR research.

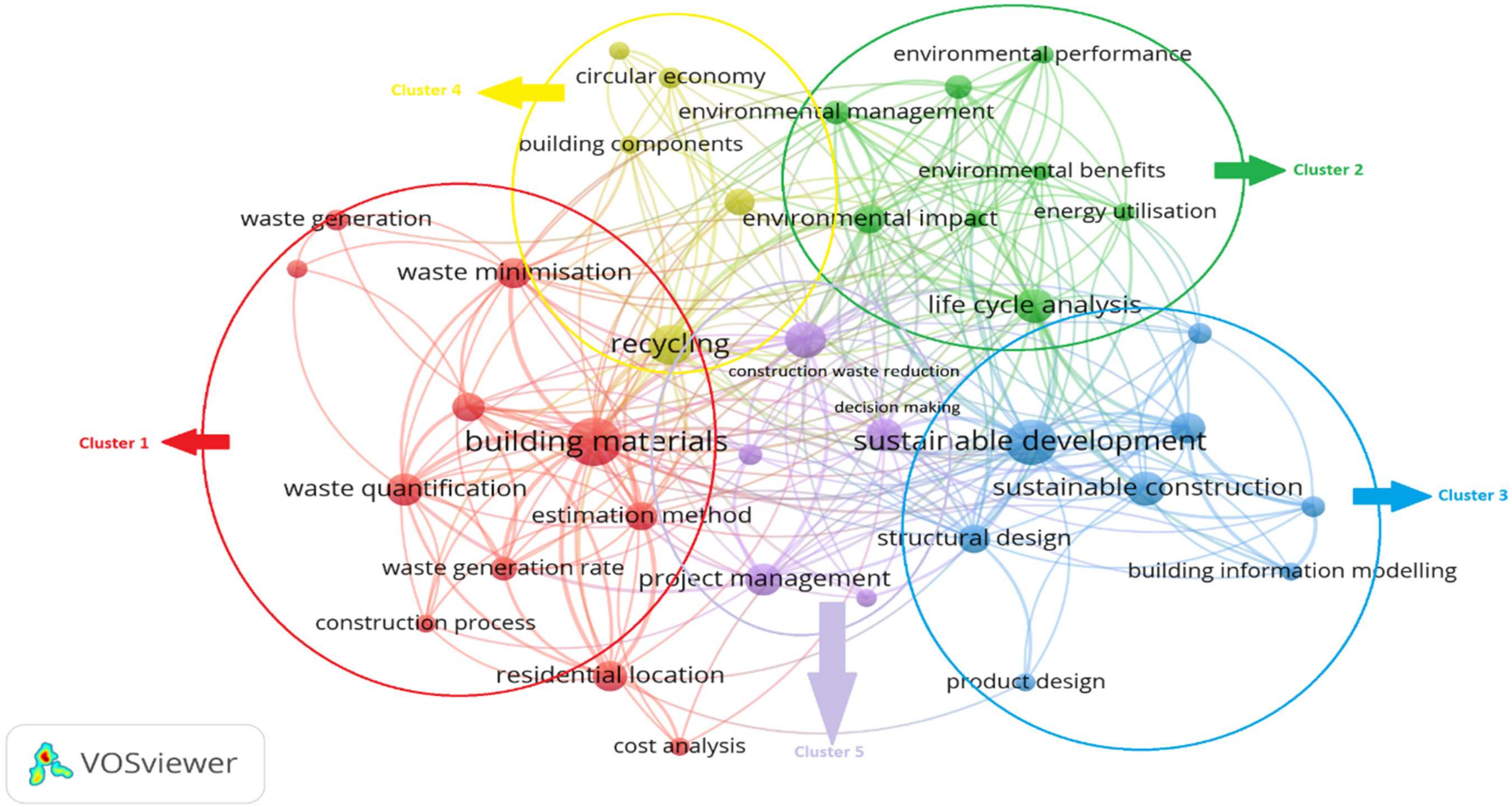

Figure 2.3: Clusters based on keyword occurrences map

Figure 2.4 represents the density visualisation that distinguishes the keywords of interest in RCWR research from the other terms (Ranjbar-Sahraei & Negenborn, 2017). The red-hot spot areas with the highest occurrence of keywords are building material, sustainable development, recycling and sustainable construction. These keywords are pivotal due to their distinct contributions to RCWR and their prevalence in advancing novel research.

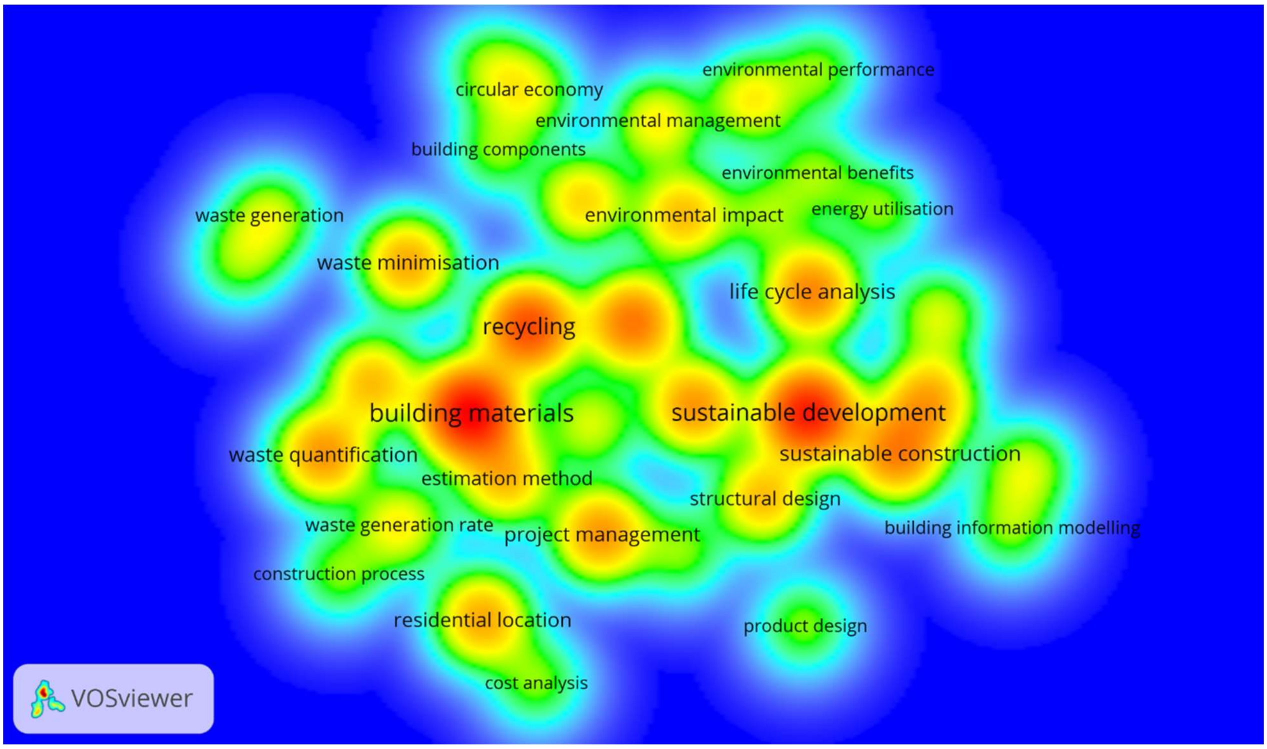

Figure 2.4: Density visualisation for the keywords of interest in RCWR research

To complement the keywords cluster analysis, Figure 2.5 illustrates the evolution of the keywords for the RCWR research to understand the trend of the research timeline and determine future research directions (Ranjbar-Sahraei & Negenborn, 2017). A significant increase in publications after 2016 could be due to the United Nations issuing the globally adopted 2030 Agenda for Sustainable Development. The rise in publications and the frequency of relevant keywords indicate the ongoing efforts to align RCWR research with achieving sustainable development goals (SDGs). The recent and future hot spot keywords in research themes are circular economy in Cluster 4, decision-making in Cluster 5 and building information modelling (BIM) in Cluster 3 (see Figures 2.3 and 2.5).

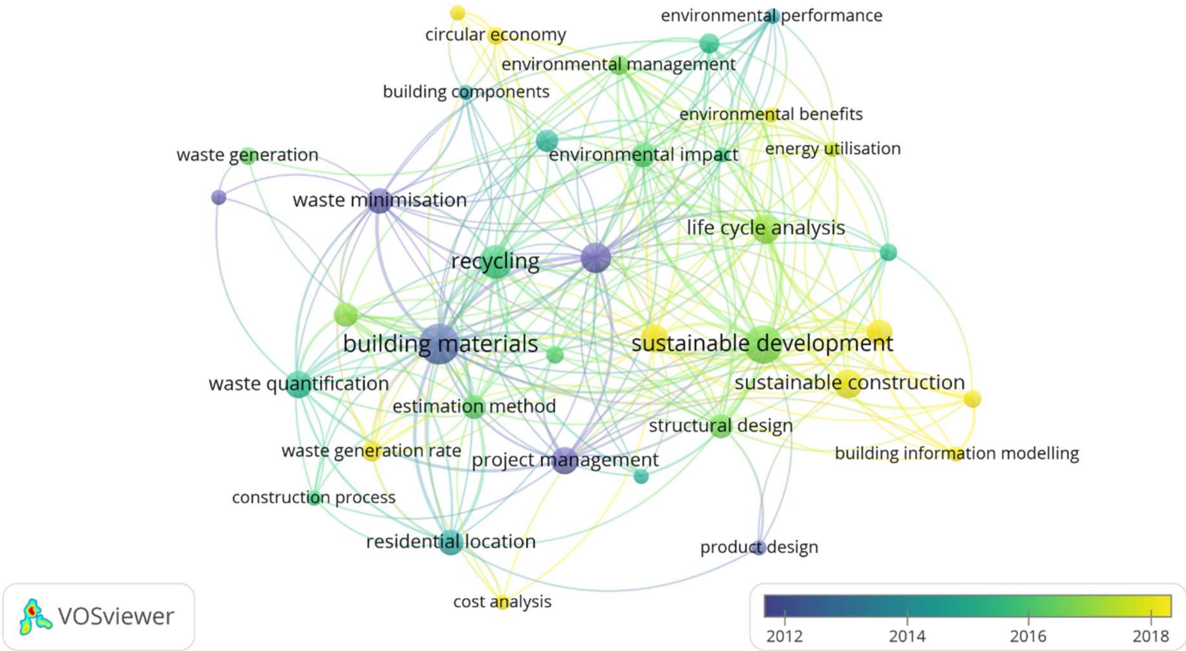

Figure 2.5: The evolution of the keywords of interest in RCWR research

2.4.2 Cluster 1: Waste generation and management performance

Several studies have suggested that estimating CW is critical information in decision-making regarding CW management performance. A pivotal study by Seeboo (2022) revealed that CW generation and waste management performance are affected by decisions related to the characteristics of residential design, mainly the selection of building materials and the floor area size. Domingo and Batty (2021) argued that estimation methods of CW generation have limitations due to the differences in design, construction methods and building materials in various residential projects. Therefore, researchers have formulated estimation methods and identified indicators to examine CW generation and understand the effects on CW management performance. The floor area is the most widely used indicator for estimating CW generation in RCWR literature. A few examples are Sáez et al. (2014), Sáez, Porras-Amores and del Río Merino (2015), J. Li et al. (2013), and Domingo and Batty (2021), developed CW generation rates based on the weight of waste per floor area. In addition, Fernandes da Paz, Vaz Lafayette and Sobral (2019) highlighted that waste generation and floor area size are inversely related. However, Maués et al. (2020) described the number of floors as a prime indicator for CW generation. Furthermore, Wang et al. (2020) found that CW generation rates vary at the same construction stage because of the differences in construction methods applied. Therefore, the advice of including indicators for CW generation by construction stage, introduced by Fernandes da Paz, Vaz Lafayette and Sobral (2019) and Katz and Baum (2011), is a valid argument.

Numerous studies have been published within the nomenclature keyword 'waste quantification', which comprehends estimating, forecasting or quantifying CW generation (Maués et al., 2020). Forecasting CW generation is a vital requirement of the project waste management plan that enables designing informed and early RCWR goals and strategies (Maués et al., 2020; Quiñones et al., 2021). A practical and project-specific waste management plan that includes all construction phases is significant in optimising RCWR (Poon et al., 2004; Ratnasabapathy, Alashwal, & Perera, 2020). For instance, the availability of data about CW quantity and composition provides the correct information for waste reduction planning before commencing construction work. It guides the formulation of policies and prioritisation of waste management strategies (Mália et al., 2013; Subramaniam et al., 2018). In addition, correct and rich information about the CW type, quantity and construction stage helps identify proactive measures for high-priority waste materials and allows benchmarking sustainable residential construction practices (Kelly & Hanahoe, 2008; Sáez, Del Río Merino, & Porras-Amores, 2012).

Tailoring an RCWR plan should aim for an adequate selection of building materials that reduce waste generation and energy and raw materials consumption (Bissoli-Dalvi et al., 2016). A suitable selection of residential building materials establishes efficient CW reduction and improves the overall environmental benefits (Cherian et al., 2020). Thus, the concept of material control in RCWR has been introduced by optimising the design, procurement and installations, and on-site management strategies (Poon, Yu, & Jaillon, 2004). Building materials have received intense research interest concerning the relation to RCWR; see Figures 2.4 and 2.5. Identifying indicators for residential building materials optimises waste reduction and helps benchmark the most wasteful and challenging materials to reduce (Mahpour, Alvanchi, & Mortaheb, 2019). A deeper understanding of residential locations' characteristics, particularly land-use regulations and geographical characteristics (Fulton et al., 2020; Umar, Shafiq, & Isa, 2018), supports sustainable construction practices that positively benefit waste and cost reduction. The residential project's time and cost, choice of materials, technological aspects and design are the barriers to adopting sustainable practices (Poon, Ann, & Ng, 2003). Since residential construction projects are time-critical, the RCWR plan must consider the time factor and apply procurement strategies focused on waste reduction (Tam, Tam, & Ng, 2007).

2.4.3 Cluster 2: Prefabrication and LCA concepts in RCWR

The existing conventional methods and building materials in residential construction are causing considerably severe environmental impacts (Wang et al., 2020). Prefabrication is receiving growing interest as a residential construction method that supports waste reduction at the source and enhances sustainable environmental performance (Hao et al., 2021; Jiang et al., 2019; Zhai, Reed, &

Mills, 2014b). Unlike conventional methods, prefabrication in residential construction is significant for achieving sustainable development due to balancing environmental and economic benefits (Nan & Jie, 2020). Furthermore, using prefabricated components in residential construction has benefits (Hao et al., 2021) in (i) achieving effective RCWR, (ii) reducing the cost of CW management, and (iii) minimising the environmental and social impacts of CW.

A detailed examination of prefabricated materials in residential construction showed a significant reduction in materials use and contributed to low energy consumption (Cherian et al., 2020). Likewise, Kedir and Hall (2021) suggested that materials designed through prefabrication improve the overall residential project lifecycle by contributing to RCWR and materials consumption. However, Sáez et al. (2014) pointed out that packaging waste hindered efficient waste reduction when using prefabricated material. Hence, the study suggested optimising procurement strategies by pursuing less packaged materials, complying with manufacturing guidelines for material transportation and installation, partnering with suppliers to reduce waste, and performing on-site reduction strategies. The prefabrication technique of precast design in structural elements has achieved RCWR successfully. However, one problem with this technique is the limited application to only residential designs of repetitive and standard features (Baldwin et al., 2009). Moreover, steel and timber prefabricated structures are proven to achieve satisfactory waste reduction and energy efficiency rates (Aye et al., 2012).

Moreover, the concept of LCA emerged recently and is generally employed to evaluate the environmental impacts or benefits of residential construction methods and materials. For example, Kakkos et al. (2020) employed LCA to evaluate the potential of utilising waste materials as secondary resources in residential construction. On the one hand, it contributes to RCWR; on the other hand, it maximises environmental protection and energy efficiency. Llatas et al. (2021) argued that existing research using the LCA method is particularly interested in evaluating the benefits of non-prevention measures that deal with CW after being produced, which requires waste treatment methods such as recycling and reuse. The study endorsed scenarios focusing on preventing waste before it is generated by designing and implementing RCWR strategies at the source.

2.4.4 Cluster 3: Design concepts in RCWR

The concept of sustainable construction includes the principles of economic, environmental and social sustainability (Tatjana et al., 2021). Thus, residential design decisions must respond to people's needs and maximise the environmental and economic benefits. On the other hand, design decisions in RCWR are associated with material selection (Seeboo, 2022) and achieving source reduction needs efficient design approaches such as design for deconstruction and prefabrication (Ratnasabapathy, Alashwal, & Perera, 2020).

The design for the RCWR approach observed in studies applied the concept of information theory, thus incorporating mathematical algorithms to optimise waste reduction in design. For example, Manrique et al. (2011) applied such an approach in frame design and endorsed a wood waste reduction result. The study concluded that material waste reduction contributes to economic and environmental benefits, which promotes sustainable construction. However, using algorithms could increase complexity and limit the method's applicability. Another application is the barcode approach to control and reduce on-site CW through incentives (Li, Chen, & Wong, 2003).

BIM is an assessment tool helpful in managing digitised data across the project lifecycle and guiding design decision-making (Georgiadou, 2019). BIM's benefits are optimising design planning and reducing material waste (Liu et al., 2018), such as developing material passport tools with BIM (Honic, Kovacic, & Rechberger, 2019). A material passport is a tool that details building material installation during construction and recovery alternatives at the end-of-life stage (Atta, Bakhoum, & Marzouk, 2021). Software tools, such as BIM, enhance the design process and RCWR performance. For example, Quiñones et al. (2021) proposed that BIM is a valuable tool for estimating CW during the early design stages. Furthermore, Georgiadou (2019) argued that existing research repeatedly addressed BIM advantages in promoting collaboration and integration of innovative processes despite the benefits of BIM in RCWR.

Poor design decisions contribute 30% of generated CW (Seeboo, 2022). Specifically, design decisions related to the residential build design and structural components. Material waste reduction could be achieved by optimising the architectural panels' design and manufacturing process (Rausch, Sanchez, & Haas, 2021). Lekan and Segunfunmi (2018) and Wang et al. (2020) supported this view and indicated that efficient designs requiring no design alteration or rework significantly reduce CW. Residential design approaches adopting information modelling enable designers to visualise complex design and construction processes, leading to more efficient design approaches (Baldwin et al., 2009). In addition, considering LCA in terms of cost, environmental, and social impacts supports informed decision-making by designers (Baldwin et al., 2008).

Another efficient design approach is 3DP technology. The implementation of 3DP technology has been endorsed in obtaining sustainable residential construction design (Singh et al., 2021; Zhang et al., 2019). However, the main limitation of 3DP is that the printability and quality of 3D printed material depend on the functionality and mechanical features of the required material, presenting a potential limitation (Zhang et al., 2019). To overcome this limitation, the quality of mixed materials and printing specifications can be improved to enhance printability. 3DP offers several benefits to sustainable residential construction practices, including waste reduction and the ability to produce materials with high-precision design characteristics, resulting in reduced construction costs and increased efficiency (Tahmasebinia et al., 2020; Tahmasebinia et al., 2018).

2.4.5 Cluster 4: Circular economy

The central theme in this cluster is that the transition into a circular economy is facilitated by achieving RCWR and developing sustainable construction practices that promote recycling and efficient resource consumption (Quiñones et al., 2021). Furthermore, the shift into applying the concepts of circular economy to stages of materials manufacturing and residential design and construction will achieve higher rates of reusing and recycling and lead to RCWR instantly (Shooshtarian, Hosseini, et al., 2021). The interest in the circular economy concept has emerged recently and is a hot research spot in RCWR; see Figures 2.4 and 2.5.

Performing efficient recycling and reduction strategies starts with a CW management plan in the design phase that includes incentives to promote implementation (Kakkos et al., 2020). Alternatively, for on-site practices, CW sorting is the best way to optimise the number of recycled materials (Sáez et al., 2014). Hence, allocating an adequate number and size of bins in working site areas is significant to recycling practice (Sáez et al., 2014). Consequently, poor site management practices hinder efficient waste data collection, and recycling decisions are cost-driven instead of environmental benefits (Lau, Whyte, & Law, 2008). At the same time, cost minimisation is a direct benefit of waste reduction (Bossink & Brouwers, 1996). A further suggestion is to identify and prioritise materials for recycling in the waste management plan (Boser & El-Gafy, 2011).

Enhancing CW sorting, promoting financial incentives for recycling, and imposing fees on CW landfills were suggested to boost the economic performance of RCWR (Hao et al., 2019). Moreover, integrating multiple waste reduction strategies would achieve more desirable outcomes in RCWR (Hao et al., 2019). A key concept in recycling is enabling the recovery of materials wastes and keeping them in use, establishing the linkage between recycling, circular economy and RCWR (Arab, Farrokhzad, & Habert, 2021). Waste trading is another RCWR strategy, allowing material wastes to be reused, recycled and recovered from landfills (Ratnasabapathy, Alashwal, & Perera, 2020). Thus, waste trading promotes circularity and efficiency by reselling and exchanging waste materials, coupling value with waste.

Preventing waste generation, also termed waste prevention, is the optimal objective over recycling and could be enhanced through the design phase. However, recycling could be challenging for some materials, such as wood waste, because the contamination risk requires high technological innovation and cost to facilitate materials recovery (Kern et al., 2018). Thus, investigating and evaluating influential factors concerning residential design and on-site installation of wood materials helped implement strategies that resulted in significant waste reduction.

Facilitating the reusing of building components and materials reduces CW and allows for recycling to enhance the potential of circularity (Arora et al., 2019; Lehmann, 2012). Furthermore, understanding the material flows of residential construction opens new ways to how waste is created and what construction methods need to be optimised, which could significantly reduce waste and change the industry's behaviour. Material flow analysis assesses the stock and flow of building materials, CW generation and material recyclability in residential construction (Condeixa, Haddad, & Boer, 2017; Tazi, Idir, & Fraj, 2021). In addition, the method helps examine the circularity potentials of residential building materials. Information collected about the consumption, use and landfilled residential building materials offers new perspectives in evaluating the construction processes and improving source reduction strategies (Tazi, Idir, & Fraj, 2021).

2.4.6 Cluster 5: Decision-making concepts in RCWR

The highlight of this cluster is that developing decision-making tools to support sustainability and RCWR in residential construction should include environmental, economic and social indicators along with stakeholder satisfaction. Improving decision-making in designing and selecting building components enhances sustainability performance and RCWR. Gilani, Pons and de la Fuente (2022) developed a tool to assess sustainability in facade design and selection, emphasising stakeholder integration and bias elimination in indicator definition.

The social criteria are often overlooked in decision-making tools for sustainability in residential construction. Shooshtarian, Hosseini, et al. (2021) highlighted the need to understand end-users requirements in residential construction decision-making and sustainable planning. Following this concern, the study suggested that current decision-making frameworks have become inadequate because of the failure to assess the social aspect of sustainable residential construction. A decisive aspect of social sustainability indicators in residential construction is the functionality and resilience of the architectural residential design (Fatourehchi & Zarghami, 2020). Therefore, making decisions related to the environmental sustainability of design, which includes RCWR, must consider end-user satisfaction with the architectural design.

The rise in environmental awareness and costs associated with CW management necessitates sustainable decision-making in residential construction practices (Gavilan & Bernold, 1994). The study suggested that decision-makers need information about sources of CW to assess efficient planning for source reduction. Furthermore, Gavilan and Bernold (1994) argued that indicators representing environmental criteria have limited effect in most decision-making models because of the challenging environmental impact quantification.

Current environmental assessment tools have limited performance due to differences in issues, criteria and weighting (Wallhagen & Glaumann, 2011; Wu et al., 2016). For example, Yan, Lai and Lin (2012) challenged the decision-making assessment criteria in green residential buildings for allocating higher weight to energy efficiency than CW reduction. In addition, multiple stakeholders with different interests are responsible for creating residential construction for environmental benefit (Wallhagen & Glaumann, 2011). RCWR is one of the environmental benefits of applying innovation in residential construction (Sitek & Tvaronavičienė, 2021). However, the cost could hinder the implementation of RCWR practices; hence, it is vital to budget the CW management cost earlier in project planning (Jingkuang, Yousong, & Yiyong, 2012; Sun et al., 2019; Umar, Shafiq, & Isa, 2018). For example, Liu et al. (2019) indicated that integrating budgeting for CW reduction in bidding is valuable in informed decision-making because of assigning responsibilities, realising the economic benefits of RCWR and promoting efficient recycling-reusing strategies.

Sufficient RCWR can be enhanced through adequate project management strategies such as efficient material time delivery and storage and sustainable procurement to prevent loss and enhance material reuse (Umar, Shafiq, & Isa, 2018). In addition, improvement in waste management practices requires support in regulation, policy formulation and innovative technology, which incorporate a responsibility to multiple stakeholders. An earlier study, by Jaillon and Poon (2008), aimed to assess prefabrication's sustainable aspects (economic, environmental and social). Results indicated that an associated increase in cost when adopting a sustainable construction method is balanced by reducing waste, time and site activities, resulting in improved quality and environmental performances.

2.5 Communication

The identified vital themes provide an in-depth understanding of the state of the art in RCWR, which comprehensively addresses RQ1. The analysis also sheds light on sustainable construction practices for achieving RCWR in response to RQ2. In response to RQ3, 'RCWR benefits' and 'RCWR barriers' sections identify and explore the barriers and benefits integral to implementing RCWR, offering valuable insights for overcoming challenges and maximising benefits.

2.5.1 Themes and sub-themes comprising RCWR

The presented literature review generated interconnected themes and sub-themes that comprise RCWR concepts, as illustrated in Table 2.1. After identifying and interpreting the dominant theme of each cluster, more specific sub-themes were derived and categorised. Quantifying CW was found to be a necessary step preceding design, as valuable information about the material waste composition and weight is critical in design features. Thus, materials of higher waste profile could be prioritised, and construction methods could be evaluated to avoid wasteful features and optimise RCWR earlier in design. Consequently, design decisions characterise the weight and composition of residential CW.

Moreover, concepts related to residential design decisions can be categorised into construction methods and building materials. These aspects must be assessed based on economic, environmental and social principles to ensure sustainable construction. A key finding is that residential design decisions must respond to stakeholders' needs and maximise the environmental and economic benefits. To address policy and regulation issues, stakeholders' satisfaction is required to guide RCWR. However, RCWR needs more legislation and an incentive strategy. The review also revealed a lack of engagement and understanding of stakeholders' roles in RCWR, which hinders collaboration and partnerships.

The literature suggests that optimising residential design, promoting material recyclability and reducing waste directly benefit RCWR and the circular economy transition. The analysis reveals that sustainable construction practices supporting RCWR design include BIM, 3DP, design for deconstruction and prefabrication or off-site manufacturing. Implementing these practices has led to high rates of source waste reduction and less waste sent to landfills. Recycling has also been recognised as a sustainable practice contributing to RCWR and the circular economy. However, waste avoidance through implementing design for waste reduction practices is essential for RCWR. In addition, effective waste management planning during the initial stages of residential construction projects can contribute to better RCWR performance. Therefore, sustainable procurement strategies and on-site practices, particularly waste sorting, are encouraged and recognised as effective measures for increasing RCWR rates.

The environmental assessment based on the two primary concepts of environmental benefit and impact is critical to decision-making. LCA is the most sustainable and effective practice for pursuing environmental assessment. However, the review suggests that the environmental assessment should be through the project lifecycle and against unique criteria for RCWR.

Table 2.1: Themes and sub-themes comprising RCWR

Themes	Sub-themes	References
Waste generation and management planning.	Benchmark to materials of high waste profile.	Seeboo (2022); Domingo and Batty (2021); Sáez, Del Río Merino and Porras-Amores (2012); Kelly and Hanahoe (2008); Mália et al. (2013); Poon et al. (2004); Ratnasabapathy, Alashwal and Perera (2020); Maués et al. (2020); Wang et al. (2020); Katz and Baum (2011); Quiñones et al. (2021); Bissoli-Dalvi et al. (2016); Sáez et al. (2014); J. Li et al. (2013); Fernandes da Paz, Vaz Lafayette and Sobral (2019); Mahpour, Alvanchi and Mortaheb (2019); Sáez, Porras-Amores and del Río Merino (2015)
	Avoid wasteful practices.	Cherian et al. (2020); Poon, Yu and Jaillon (2004); Poon, Ann and Ng (2003); Fulton et al. (2020); Umar, Shafiq and Isa (2018)
	Project-specific waste management plan with an RCWR target.	Poon et al. (2004); Ratnasabapathy, Alashwal and Perera (2020); Maués et al. (2020); Quiñones et al. (2021); Bissoli-Dalvi et al. (2016); Tam, Tam and Ng (2007); Sáez, Porras-Amores and del Río Merino (2015); Subramaniam et al. (2018)
Prefabrication and LCA concepts.	Prefabrication is significant for achieving RCWR and satisfactory energy efficiency rates.	Wang et al. (2020); Hao et al. (2021); Jiang et al. (2019); Zhai, Reed and Mills (2014b); Nan and Jie (2020); Cherian et al. (2020); Kedir and Hall (2021); Sáez et al. (2014); Baldwin et al. (2009); Aye et al. (2012)
	LCA is to evaluate the environmental impacts or benefits of residential construction methods and materials.	Kakkos et al. (2020); Llatas et al. (2021)
Design concepts.	Design for RCWR.	Manrique et al. (2011); Li, Chen and Wong (2003); Tahmasebinia et al. (2018); Tahmasebinia et al. (2020); Tatjana et al. (2021); Seeboo (2022); Ratnasabapathy, Alashwal and Perera (2021); Georgiadou (2019); Liu et al. (2018); Honic, Kovacic and Rechberger (2019); Atta, Bakhoum and Marzouk (2021); Quiñones et al. (2021); Rausch, Sanchez and Haas (2021); Lekan and Segunfunmi (2018); Wang et al. (2020); Baldwin et al. (2008); Baldwin et al. (2009); Singh et al. (2021); Zhang et al. (2019)
	Implement sustainable construction principles in building materials selection and construction methods.	
	Improve RCWR strategies.	
Circular economy.	Facilitate recycling and reusing through materials manufacturing and residential design.	Quiñones et al. (2021); Shooshtarian, Hosseini, et al. (2021); Kakkos et al. (2020); Sáez et al. (2014); Lau, Whyte and Law (2008); Bossink and Brouwers (1996); Boser and El-Gafy (2011); Hao et al. (2019); Arab, Farrokhzad and Habert (2021); Ratnasabapathy, Alashwal and Perera (2020); Kern et al. (2018); Arora et al. (2019); Lehmann (2012); Condeixa, Haddad and Boer (2017); Tazi, Idir and Fraj (2021)
Decision-making concepts.	Stakeholders' satisfaction.	Gilani, Pons and de la Fuente (2022); Shooshtarian, Hosseini, et al. (2021); Fatourehchi and Zarghami (2020)
	Active project management.	Jaillon and Poon (2008); Umar, Shafiq and Isa (2018)
	Awareness of RCWR benefits and barriers.	Gavilan and Bernold (1994); Wallhagen and Glaumann (2011); Wu et al. (2016); Yan, Lai and Lin (2012); Sitek and Tvaronavičienė (2021); Jingkuang, Yousong and Yiyong (2012); Sun et al. (2019); (Umar, Shafiq, & Isa, 2018); Liu et al. (2019).

2.5.2 RCWR benefits

Reducing the environmental impacts of residential CW is notably recognised as a benefit and driver for New Zealand's commitment to reducing emissions and promoting sustainable development. Although several reviewed articles have not directly mentioned the benefits of RCWR, the reported benefits are related to the application of RCWR practices due to the increasing interest in evaluating the environmental impact of such practices. A summary of the benefits of achieving RCWR is reported in Table 2.2, serving as a guide for policymakers and stakeholders in New Zealand's residential construction sector to promote and implement sustainable practices of RCWR.

Table 2.2: Summary of benefits of achieving RCWR

Category	Sub-category	Author (s)
Economic benefits	Cost reduction	Dalla Zanna, Fernandes and Gasparine (2017); Lee, Kim and Kim (2016); Zhai, Reed and Mills (2014a); Han, Gao and Shao (2016); Bossink and Brouwers (1996); Tahmasebinia et al. (2018); Tahmasebinia et al. (2020)
	Improvements in productivity	Zhai, Reed and Mills (2014a); Serpell and Alarcon (1998); Zhang, Eastham and Bernold (2005); Lekan and Segunfunmi (2018); Wang et al. (2020)
	Increase competency and company's profitability.	Liu et al. (2019); Treloar et al. (2003)
Environmental benefits	Improved levels of air pollution, noise and dust.	Cao et al. (2015); Zhai, Reed and Mills (2014a); Umar, Shafiq and Isa (2018)
	Reduce environmental impacts and improve resource efficiency.	Rausch, Sanchez and Haas (2021); Bissoli-Dalvi et al. (2016); Llatas et al. (2021); Kakkos et al. (2020); Sitek and Tvaronavičienė (2021)
	Reducing the pressure on landfills	Hao et al. (2021); Ratnasabapathy, Alashwal and Perera (2020); Poon et al. (2004)
Social benefits	Improve the city image and release landfill spaces.	Gilani, Pons and de la Fuente (2022); Fatourehchi and Zarghami (2020); Zhai, Reed and Mills (2014a); Umar, Shafiq and Isa (2018); Hao et al. (2021); Nan and Jie (2020)
	Community satisfaction, minimise the risk of illegal dumping, enhanced safety of residential construction projects, and human health improvements.	
Accelerating the achievement of sustainable development and circular economy	Improves sustainable production and consumption of resources	Tazi, Idir and Fraj (2021); Arab, Farrokhzad and Habert (2021); Arora et al. (2019); Sun et al. (2019); Gilani, Pons and de la Fuente (2022); Atta, Bakhoum and Marzouk (2021); Shooshtarian, Hosseini, et al. (2021); Singh et al. (2021); Tatjana et al. (2021); Nan and Jie (2020)

For instance, Cao et al. (2015) reported that waste reduction from adopting prefabrication contributed to a reduction in resource consumption (35.82%), health damage (6.61%) and ecosystem damage (3.47%). Moreover, Nan and Jie (2020), Umar, Shafiq and Isa (2018), and Zhai, Reed and Mills (2014a) have reported improved levels of air pollution, noise and dust contributing to improvements in human health. In addition, reducing waste would reduce landfill pressure (Poon et al., 2004; Ratnasabapathy, Alashwal, & Perera, 2020) due to the increased potential for recycling and reusing building elements (Zhai, Reed, & Mills, 2014a). As a result, releasing landfill spaces improves the city's image, contributes to community satisfaction, minimises the risk of illegal dumping and improves human health.

The economic benefits of RCWR are linked to achieving cost reduction, productivity improvements and increased company competency and profitability. For example, Han, Gao and Shao (2016) reported that adopting BIM reduced material waste with a total cost saving of 4.3% and cut the project's period by 15 weeks earlier. In addition, early residential project delivery increases the competency and profitability of companies (Zhai, Reed, & Mills, 2014a). Moreover, Zhang et al. (2019) reduced up to 80% of labour costs, 60% of CW, and 70% of production time by implementing 3DP concrete. Furthermore, productivity benefits are linked to RCWR concepts of efficient design that eliminate the need for rework (Lekan & Segunfunmi, 2018; Wang et al., 2020).

Increasing research efforts are devoted to linking sustainable development, circular economy and energy efficiency with RCWR; see Figures 2.4 and 2.5. According to Singh et al. (2021), improvements in material consumption achieve the SDG of resource consumption- SDG 12. Similarly, Tazi, Idir and Fraj (2021) linked improvements in waste reduction rates and the production and consumption of raw residential construction materials to climate change mitigation, which comprises SDGs 11, 12 and 13. Furthermore, by boosting circular thinking, the consumption of raw materials is minimised, whereas manufacturing materials and end-of-life options for residential construction materials have less environmental impact.

2.5.3 RCWR barriers

For New Zealand to enable RCWR, more profound knowledge of the barriers that could hinder implementing reduction practices is required. The reviewed studies have identified various barriers from different perspectives, summarised and categorised in Table 2.3. By addressing these barriers, policymakers, researchers, and practitioners can develop effective strategies to overcome barriers and promote RCWR.

Table 2.3: Summary of barriers to achieving RCWR

Category	Sub-category	Authors
Management Barriers	Poor RCWR planning	Dalla Zanna, Fernandes and Gasparine (2017); Lee, Kim and Kim (2016); Llatas and Osmani (2016); Cao et al. (2015); Kern et al. (2015); Lau, Whyte and Law (2008); Poon, Ann and Ng (2003)
	Lack of engagement and collaboration among stakeholders	Han, Gao and Shao (2016); Ratnasabapathy, Alashwal and Perera (2020)

	Lack of information on the generation of CW	Mahayuddin and Pereira (2014); Atta, Bakhoum and Marzouk (2021); Quiñones et al. (2021); Fernandes da Paz, Vaz Lafayette and Sobral (2019); Llatas et al. (2021); Hao et al. (2021); Domingo and Batty (2021); Maués et al. (2020); Arora et al. (2019); Honic, Kovacic and Rechberger (2019); Carpio et al. (2016); Carretero Ayuso and García Sanz-Calcedo (2018); Mália et al. (2013); Kelly and Hanahoe (2008); Sáez, Del Río Merino and Porras-Amores (2012)
Economic Barriers	High cost of implementing RCWR practices	Cao et al. (2015); Poon, Ann and Ng (2003); Umar, Shafiq and Isa (2018); Hassan et al. (2015); Sun et al. (2019); Wu et al. (2016)
	Performance incentives	Shooshtarian, Hosseini, et al. (2021); Nan and Jie (2020); Mahpour, Alvanchi and Mortaheb (2019); Pericot et al. (2014)
Legislative Barriers	Policy implications	Hassan et al. (2015); Sun et al. (2019)
	Poor regulatory control	Mortaheb and Mahpour (2016); Tatjana et al. (2021); Mahpour, Alvanchi and Mortaheb (2019); Georgiadou (2019)
	Lack of standardisation for recycling and reusing materials.	Ratnasabapathy, Alashwal and Perera (2020); Tazi, Idir and Fraj (2021)
	Inadequacy of existing RCWR's decision-making	Ratnasabapathy, Alashwal and Perera (2020); Yan, Lai and Lin (2012); Fatourehchi and Zarghami (2020); Shooshtarian, Hosseini, et al. (2021)
Technology Barriers	The need for highly skilled labour	Singh et al. (2021); Tahmasebinia et al. (2018); Georgiadou (2019); Poon, Ann and Ng (2003); Bissoli-Dalvi et al. (2016)
Cultural Barriers	Poor level of awareness and education	Atta, Bakhoum and Marzouk (2021); Shooshtarian, Hosseini, et al. (2021);
	Market acceptability	Sitek and Tvaronavičienė (2021); Liu et al. (2019); Tatjana et al. (2021); Mahpour, Alvanchi and Mortaheb (2019)

2.5.3.1 Management Barriers

Enabling RCWR is being hindered by several management barriers. According to Dalla Zanna, Fernandes and Gasparine (2017) and Lee, Kim and Kim (2016), efficient planning for RCWR lacks a waste plan that includes well-defined and measurable goals and targets for waste reduction. Kern et al. (2015) suggested that waste reduction could be embedded in the arrangements and contractual documents to establish responsibility and commitment. Furthermore, the lack of information on the generation of CW has been broadly discussed. The performance of RCWR management plans and practices could be improved by understanding CW characteristics and indicators for CW generation. Furthermore, a lack of quantitative information hinders the designing of effective RCWR strategies in the residential project plan (Cao et al., 2015; Llatas & Osmani, 2016). Poor RCWR planning also includes poor site management practices critical to achieving RCWR, such as waste sorting and adequate handling of materials (Lau, Whyte, & Law, 2008; Poon, Ann, & Ng, 2003).

Stakeholders play a critical role in achieving RCWR. However, the lack of practical tools that promote stakeholder involvement in implementing the concepts of RCWR could be a barrier to building collaborations in this area (Han, Gao, & Shao, 2016; Ratnasabapathy, Alashwal, & Perera, 2020).

Hence, Gilani, Pons and de la Fuente (2022) suggested that developing a practical decision-making framework to integrate stakeholders' interests in RCWR could enhance stakeholders' involvement. In addition, recent literature criticised the lack of policy regulation and performance incentives that promote CW reduction among stakeholders (Mahpour, Alvanchi, & Mortaheb, 2019).

2.5.3.2 Economic Barriers

The economic impacts of RCWR have not been widely explored yet. For instance, Umar, Shafiq and Isa (2018), Cao et al. (2015), and Poon, Ann and Ng (2003) have reported that the high costs of implementing waste management practices could limit achieving RCWR. The increased costs are related to additional labour to sort CW on-site, given that residential projects are limited in time and cost or the associated costs of applying emerged technologies (Wu et al., 2016). Therefore, Jingkuang, Yousong and Yiyong (2012) suggested a budget plan for RCWR implementation. Moreover, Shooshtarian, Hosseini, et al. (2021) and Nan and Jie (2020) highlighted that the lack of financial incentives and the high cost of recycling hinder the adoption of sustainable practices. Hence, Nan and Jie (2020) suggested developing a rewarding scheme to overcome this barrier.

2.5.3.3 Legislative barriers

Policy formulation and regulation significantly stimulate the interest in RCWR and guide its progress (Mahpour, Alvanchi, & Mortaheb, 2019; Mortaheb & Mahpour, 2016). For example, Tatjana et al. (2021) suggested regulating the environmental impacts of construction activities, whereas Georgiadou (2019) described the legislation as the key to driving a change in the industry. Formulating effective policies and regulations needs support from decision-making tools. However, existing decision-making tools are limited to sustainability assessment in residential construction and lack a complete RCWR tool (Fatourehchi & Zarghami, 2020; Shooshtarian, Hosseini, et al., 2021). Moreover, the reviewed literature addressed that these tools have not yet fully implemented the social criteria.

Literature addressed a lack of RCWR criteria in sustainability assessment tools. For instance, Sun et al. (2019) highlighted the low weights for waste management in the green building certification tool, which limits the ability to design practical RCWR strategies. Hence, there is a need for more robust policies in green building that solely target RCWR criteria. Policies might cause implications such as rising costs and a lack of knowledge regarding the impacts of CW and the possibilities of reduction (Hassan et al., 2015). Therefore, policy formulation must focus on raising awareness and promoting knowledge in RCWR. Mahpour, Alvanchi and Mortaheb (2019) and Hassan et al. (2015) suggested motivating stakeholders about the environment and sustainable CW management practices.

2.5.3.4 Technology barriers

Emerging technologies, such as 3D printing, actively contribute to achieving RCWR. However, the specialised knowledge and highly skilled labour required to operate these technologies can increase costs and pose integration challenges with existing practices (Georgiadou, 2019; Poon, Ann, & Ng, 2003; Singh et al., 2021; Tahmasebinia et al., 2018). One suggested approach is to develop user-friendly tools that provide clear information, which can be a viable alternative to non-complex projects (Bissoli-Dalvi et al., 2016).

2.5.3.5 Cultural barriers

The poor level of awareness and education about the RCWR benefits and sustainable practices among stakeholders was found to be a barrier to the uptake of RCWR practices, creating resistance to changing the culture of conventional methods (Atta, Bakhoum, & Marzouk, 2021; Mahpour, Alvanchi, & Mortaheb, 2019; Shooshtarian, Hosseini, et al., 2021; Tatjana et al., 2021). The level of awareness and education plays a crucial role in changing the stakeholder's behaviour and the market demand towards adopting more sustainable building materials and practices (Liu et al., 2019; Sitek & Tvaronavičienė, 2021). Market demand can shape the accessibility and acceptability of RCWR in the industry.

2.6 Future Directions for RCWR in New Zealand

This section addresses RQ4 with insights that give New Zealand a clear trajectory for future directions in RCWR, guiding policy and practice. New Zealand can acquire valuable insights from prior implementations of construction practices and policies in other countries by comprehending the concepts of RCWR. Thus, New Zealand can identify areas that require improvement to make informed decisions for shifting towards a circular economy. Additionally, highlighting the future direction for RCWR can provide New Zealand with valuable knowledge and steer the development of processes and practices that emphasise long-term sustainability within the residential sector. Residential CW displays significant variations in weight and composition. These differences are attributed to various factors, such as the building's design features, construction methods and materials. Thus, informed design decisions, sustainable construction practices and early waste management planning are essential for enabling RCWR in New Zealand.

As the reviewed literature indicates, estimating CW generation is deeply rooted in design concepts and critical to RCWR planning. Identifying indicators for estimating CW is necessary to advance knowledge of the practices and materials that primarily influence CW generation. In New Zealand, the recent study by Domingo and Batty (2021) sheds light on the importance of considering factors such as the size of the residential construction project, the type of construction materials used and the construction methods employed to enhance design for waste reduction outcomes. New Zealand can enhance the adequacy of data on residential CW by implementing a standardised system with clear guidelines for quantifying and reporting waste and by regularly monitoring and evaluating the waste data to identify areas for improvement and track progress towards tailored RCWR targets.

Future research could examine the effectiveness of substituted materials and sustainable construction practices, such as prefabrication, and assess the potential benefits of achieving RCWR in New Zealand. In this regard, there has been a recent increase in momentum for using prefabrication (Brown, Sharma, & Kiroff, 2020; Ghose, Pizzol, & McLaren, 2017; Luo & Shahzad, 2020) and LCA (Moradibistouni & Gjerde, 2017) in New Zealand. Prefabrication and LCA can play a vital role in waste reduction and establishing a circular economy in residential construction. Researchers could explore the benefits of using energy-efficient and recycled building materials and construction methods to enable RCWR in New Zealand. Policy planning in New Zealand could promote RCWR through prefabrication and LCA, explore the feasibility and potential benefits of implementing circular economy principles in prefabricated components and develop guidelines and standards for sustainable prefabrication practices and materials selection. Case studies could also demonstrate the barriers and opportunities for adopting such practices in the residential sector while considering the impact of policy and regulatory frameworks on incentivising sustainable practices.

To enhance the environmental, social and economic benefits of RCWR, sustainable construction principles should be incorporated into the overall residential construction process. Various assessment tools have been created through previous research to facilitate sustainable decision-making. Nevertheless, decision-makers in New Zealand must be aware of the factors influencing RCWR and the stakeholders' interests to develop alternatives and assess trade-offs effectively. Although the literature acknowledges the presence of various stakeholders, identifying the key stakeholders in RCWR has not been established yet. Decision-makers and policy formulators in New Zealand could benefit from qualitative and quantitative research identifying and examining factors influencing the adoption of RCWR strategies.

The literature has paid limited attention to the social criteria despite the impact on residential design and waste reduction. In addition, the lack of quantitative knowledge about the economic benefits is a significant barrier to adopting circular economy principles. Therefore, stakeholders need to comprehend the economic benefits of RCWR through the lens of the circular economy model by evaluating various case studies on successful business practices.

2.7 Conclusion

The high rate of CW sent to landfills is a growing challenge to achieving strategic waste management and sustainability goals in New Zealand and many developed countries. Simultaneously, the residential construction sector has been experiencing increased criticism about generating the highest levels of CW due to the continuous surge in housing demand. Despite efforts to reduce CW, a gap in the literature exists regarding RCWR. This article employs a combined bibliometric and critical review methodology based on keyword occurrences to systematically review articles related to RCWR published in the Scopus database. The review covers 87 articles and identifies five key themes: (i) waste generation and management performance, (ii) prefabrication and LCA concepts in RCWR, (iii) design concepts in RCWR, (iv) circular economy and (v) decision-making concepts in RCWR. The analysis also highlights the importance of sustainable construction practices such as prefabrication, 3DP and BIM in achieving RCWR at the source.

Moreover, the direct environmental benefits of RCWR were identified as reducing the environmental impact of residential construction, reducing existing pollution levels and improving human health. Although the economic benefits were mainly linked to profitability and productivity, achieving RCWR supports the three tenets of sustainability (i.e. social, economic and environmental), emission reduction targets and circular economy. On the other hand, the barriers to achieving RCWR were categorised into management, economic, cultural, communication, legislative and technology barriers.

This article emphasises the importance of establishing a standardised measuring and reporting system for residential CW quantification and improving RCWR planning in New Zealand. Insights for future research and policy formulation suggest exploring the feasibility of circular economy principles in prefabricated components, developing guidelines for sustainable prefabrication practices and materials selection and conducting case studies to identify barriers and opportunities for adoption. Finally, decision-makers in New Zealand could benefit from research examining factors influencing the adoption of RCWR strategies.

Although a systematic analysis of current RCWR research has been conducted, several limitations must be acknowledged. Firstly, the sourced publications were restricted to the Scopus database, which may have limited the scope and broadness of the collected data. Secondly, there is a potential error in the data-cleaning step due to the similarity of idiomatic expressions. Thirdly, the threshold for keyword co-occurrences was set at three occurrences, which may have influenced the clustering and visualisation of the keywords if a different threshold had been used. Additionally, the publication trend suggests an annual increase in recent years. Future research could focus on publications after March 2022 to enhance recent findings in RCWR.

The findings of this review offer comprehensive knowledge of the concepts and trends in RCWR research. This review provides valuable insights for researchers and practitioners seeking to advance sustainable practices, deepen their understanding of waste reduction in the residential construction sector and for policymakers looking to formulate policies supporting RCWR's future strategies. By addressing these limitations and utilising the knowledge gained from this review, there is potential to make further progress towards achieving more sustainable and efficient RCWR practices in New Zealand.

Chapter 3 Stakeholder Interactions and Contributions to Effective Residential Construction Waste Reduction: A Systematic Literature Review

3.1 Prelude

The surge in residential construction work in New Zealand and worldwide is leading to a significant amount of waste, necessitating collaborative efforts and effective reduction strategies. Residential construction waste reduction (RCWR) is a complex process involving various stakeholders. However, stakeholder involvement can lead to challenges in decision-making and inefficient contributions to RCWR, as indicated in Chapter Two. In this research paper, we aim to identify and analyse the roles and contributions of different stakeholders in RCWR. The analysis included eighty-nine papers obtained through a systematic literature review, which identified eight stakeholder roles in RCWR: (i) Client, (ii) Designer, (iii) Contractor, (iv) Supplier, (v) Subcontractor, (vi) Project manager, (vii) RCWR services provider and (viii) Regulator. The analysis proposes a stakeholder conceptual model of RCWR that includes the stakeholder's role, contribution, and interaction to guide and inspire future direction in RCWR planning. These findings imply that a conceptual view of RCWR stakeholders' interaction is vital to understanding their interactions and contributions, which can improve the system processes and aid in exploring effective RCWR strategies. The research provides a reference point for future academic work in construction management and presents novelty for exploring stakeholders' perspectives in RCWR.

3.2 Introduction

The construction industry accounts for 40% of global waste (Datta et al., 2022). This alarming statistic, coupled with the rapid population growth and subsequent increase in residential construction, underscores the criticality of construction waste (CW) generated (Tang et al., 2021). The value of residential construction work in New Zealand has historically represented the highest proportion among all sectors (Ministry of Business, Innovation and Employment, MBIE, 2023). According to the Building Research Association of NZ-BRANZ (2024), CW accounts for up to 50% of total waste in landfills. Moreover, New Zealand's waste strategy emphasises the importance of a cohesive approach to achieve rapid improvements, calling for a unified plan and increased collaboration among stakeholders to bolster accountability and responsibility (Ministry for the Environment- MfE, 2023b).

The urgency for effective residential construction waste reduction (RCWR) in New Zealand and other developed countries necessitates actively developing and implementing strategies and practices at every stage of the construction process (Ajayi et al., 2015). However, RCWR is a complex task requiring interaction between diverse stakeholders (Kang et al., 2022; Marshall & Farahbakhsh, 2013). The involvement of these stakeholders with multiple roles and dynamics inhibits effective decision-making due to identified challenges such as higher costs, stakeholders' misperceptions, poor communication and confusion, and inadequate planning (Ahmed & Zhang, 2021; Kang et al., 2022).

'Stakeholder(s)' is any party, whether an individual or group, with an interest or concern that can affect or be affected by the fulfilment of an organisation's objectives (Freeman & McVea, 2005). Key stakeholders are individuals whose decisions can significantly influence the success of a project or plan (Grilli et al., 2015). Hence, identifying the roles of key stakeholders is crucial to understanding their interactions and contributions to prevent potential conflicts of interest during complex decision-making processes (Benn, Abratt, & O'Leary, 2016; Mojtahedi & Oo, 2017). An integrated strategic approach among multiple groups of stakeholders has been acknowledged in addressing complicated managerial issues related to CW (Hu et al., 2019). Identifying stakeholders and their unique roles supports stakeholder contribution to enhance RCWR (Bal et al., 2013; Kabirifar et al., 2020). The performance in CW reduction should be considered based on understanding stakeholders' roles and interconnection among them. This understanding can lead to the development of tailored policies and incentives for encouraging waste reduction (Ajayi & Oyedele, 2017).

According to Zhao (2021), CW management involves key stakeholders such as contractors, clients, designers, governments, recycling companies, and the public. Ma and Hao (2024) also identified the government, CW treatment companies, clients, designers, and contractors as crucial actors in achieving circularity in the CW management system. While the studies identified similar groups of stakeholders, the construction project scope can impact the involvement and effectiveness of stakeholders in the CW management practice (Zhao, 2021). Hence, despite their relevance in CW management, RCWR stakeholders still need to be defined, as most existing studies conceptualise them within the context of construction and demolition waste management. Several studies have introduced the concepts of RCWR and highlighted the research gap related to stakeholders' roles in RCWR, which is the focus of this research paper. Identifying stakeholders' roles can amplify their involvement and foster collaboration, thereby paving the way for achieving sustainability objectives and augmenting awareness among the stakeholders about RCWR (Marshall & Farahbakhsh, 2013; Thabrew, Wiek, & Ries, 2009).

This research, therefore, aims to systematically review and synthesise the evidence on the role of stakeholders in RCWR. The objectives are (i) to identify and analyse the interaction and contributions of stakeholders in RCWR and (ii) to present recommendations for the future direction of RCWR in New

Zealand. The potential benefits of stakeholder identification in RCWR guide and inspire future exploration of the stakeholders' perspectives on the factors influencing RCWR. The research contributes to creating awareness among stakeholders about their roles and responsibilities in RCWR, fostering increased cooperation and collaboration. Ultimately, the research serves as a reference for future construction management scholarship and offers new opportunities for exploring RCWR, which contributes to a sustainable built environment.

3.3 Methodology

Systematic Literature Review (SLR) has become a more popular method in recent years for providing an unbiased and comprehensive assessment of the existing literature on a particular topic. This research designed an SLR using thematic analysis to identify stakeholders. The review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method to screen and analyse the papers selected from the Scopus database. This approach ensures transparency in the literature selection process and improves the review's reporting quality (McGrath et al., 2017). Per the PRISMA protocol, the paper extraction process is shown in Figure 3.1.

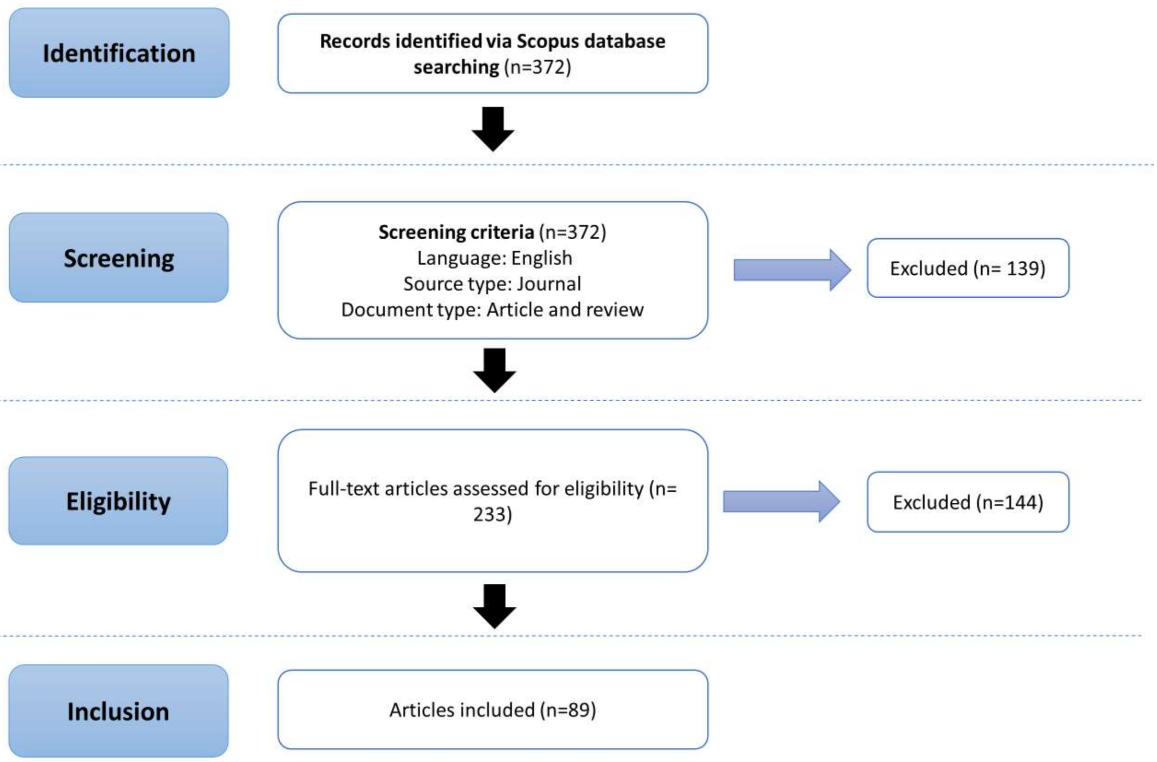

Figure 3.1: Flowchart of PRISMA systematic review process (n= the number of articles)

3.3.1 Identification and screening

The search criteria include keywords based on the research focus on RCWR using two sets of search terms from the Scopus database. The first set of search terms consists of words related to residential construction; the second is associated with CW reduction. Accordingly, a total of 13 search terms were used as follows: ((("construction waste" OR "construction and demolition waste" OR "material* waste*" OR "waste reduc*" OR "waste management" OR waste minimi*" OR "minimi* waste" OR "waste preven*" OR "reduc* waste" OR "prevent* waste" OR "3rs principle" OR "source reduc*") AND ("residential build*" OR "hous* construction" OR "hous* build*" OR "residential construction"))). The document search was conducted by topic, covering each article's title, abstract, and keywords to retrieve the maximum number of articles available in the database. The search concluded on 26 October 2023, and 372 articles were retrieved.

Screening criteria, including language, source type, and document type, were applied to ensure the relevance and quality of articles. Due to the dominance of the research content in English, only English-language articles were considered. After applying these filters, 139 articles were excluded, and 233 articles were obtained for analysis.

3.3.2 Eligibility and inclusion

The next step was to assess the eligibility of the 233 resulting articles through abstract reading and then full-text reading. The review considered articles addressing CW reduction in residential construction and related areas such as prefabrication and recycling, excluding those focused on demolition or renovation wastes. After assessing the articles, 144 were further excluded, and the total number of articles included was 89, determined based on the research aim and the evidence sought through the literature.

3.4 Results

3.4.1 Identified categories of stakeholders in RCWR

Figure 3.2 provides a comprehensive breakdown of the stakeholder roles involved in RCWR, which are discussed in the subsequent sections.

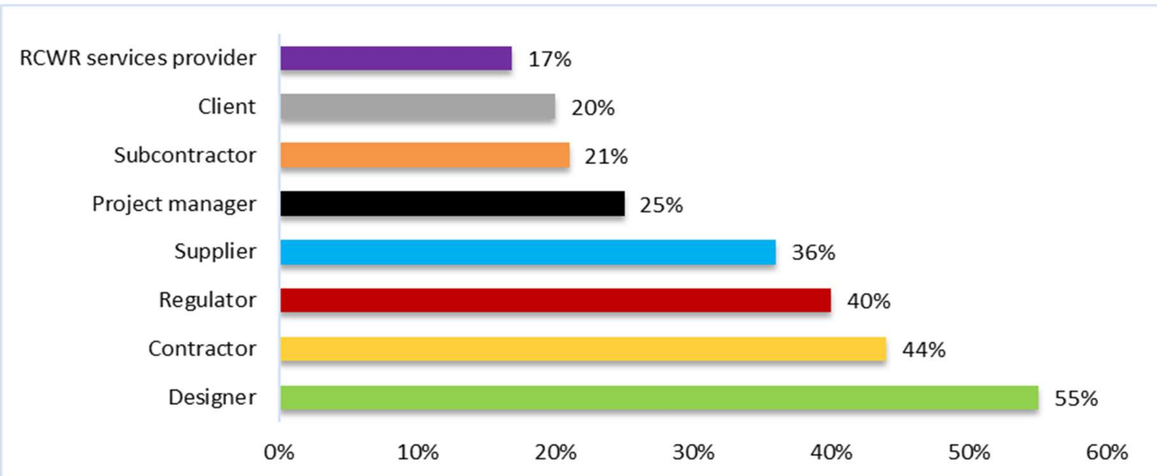

Figure 3.2: Stakeholder categories in RCWR: Percentage Breakdown

3.4.2 Client

The "client" in RCWR refers to the project owner who initiates a residential project. Residential projects are usually owned by private clients (Tahmasebinia et al., 2018), such as homeowners or investors, or by public clients, such as the government, in social housing (Georgiadou, 2019; Poon et al., 2004). While the client's representation may be low in the literature, 20% (see Figure 3.2), their role in kickstarting the residential project with an RCWR objective is pivotal, underscoring their indispensability in the RCWR process. The client appoints the designer and contractor to design, operate, and oversee the construction process. Hence, the client is responsible for providing all the requirements and necessary details related to the construction and design of the building (Hao et al., 2021; Poon et al., 2004). Also, clients are expected to pay for the design on time and verify the designer's qualifications before awarding the design bid to ensure that the quality of work is not compromised due to a lack of motivation (Mahamid, 2023). Accordingly, the client's knowledge and interest in RCWR can significantly influence decision-making during the planning, design, and construction processes.

The client's recognition of the value and benefits drives the implementation of RCWR practices (Georgiadou, 2019; Lekan & Segunfunmi, 2018). Early involvement of client leadership in design and supply chain development fosters a collaborative culture that enhances RCWR (Georgiadou, 2019). Decisions regarding RCWR are often driven by reducing costs and generating higher profits. However, a profit-driven approach does not always align with environmental benefits, creating challenges and trade-offs in decision-making (Hossain & Ng, 2020; Maués et al., 2020; Sáez, Del Río Merino, & Porras-Amores, 2012). At the same time, financial sustainability is a primary consideration for clients striving to implement circular CW management practices, especially in low-income economies (Ferronato et al., 2023).

3.4.3 Designer

Designers hold the highest degree among all categories, reported in the literature, at 55% (see Figure 3.2). The designer's role in RCWR involves designing, reviewing, and preparing detailed design documents to reduce errors and rework (Mahamid, 2023). According to Seeboo (2022), the designer should decide and finalise the selection of materials to optimise planning and reduce CW generation. Nevertheless, designers must understand and evaluate the potential savings that will arise from their decisions and the implications of these decisions on the design and construction process (Arora et al., 2020; Baldwin et al., 2008; Tatjana et al., 2021). Designers have various priorities: functionality, aesthetics, cost, environmental impact, and client satisfaction. Balancing the project priorities to achieve RCWR requires innovative thinking, careful consideration of the materials and technologies applied in construction, proactive planning, and a deep understanding of the interconnection among the project elements (Bajad, 2022; Lehmann, 2012; Vitale et al., 2018).

The innovative use of technology in design facilitates RCWR by promoting participatory design, modelling CW quantification, and design standardisation (Tu et al., 2023). Designers employing assisting tools can improve RCWR in the design phase by analysing, visualising, and proposing corrective measures to increase construction efficiency (Mahamid, 2023; Quiñones et al., 2022). For example, building information modelling (BIM) and artificial intelligence (AI) tools assist designers in predicting CW generation and identifying wasteful activities before construction begins (Gulghane, Sharma, & Borkar, 2023a; Quiñones et al., 2021). Designers who take leadership roles in managing design, standardising processes, developing shared metrics and investing in training can ensure the successful implementation of RCWR (Georgiadou, 2019). Such roles allow designers to visualise and explore ways to increase construction efficiency and incorporate environmental considerations in projects (Quiñones et al., 2022).

Designers are the decision makers for the construction decisions related to the construction method and choice of material in the design phase. Residential design characteristics significantly impact RCWR efficiency (Carpio et al., 2016; Domingo & Batty, 2021). Implementing sustainable design practices and adaptable construction methods, such as using recycled materials and designing for deconstruction, positively affects RCWR (Atta, Bakhoum, & Marzouk, 2021; Baldwin et al., 2008; Braulio-Gonzalo, Jorge-Ortiz, & Bovea, 2022; Zhai, Reed, & Mills, 2014a). Sustainable design approaches should be prioritised due to the ability to create virtually zero-waste buildings (Sassi, 2006). Design coordination between components for walls and floors in residential structures is necessary to ensure successful RCWR (Baldwin et al., 2008). Considering factors such as choice of materials, prefabrication and modularisation, efficient use of space can result in cost savings, improved environmental performance, and increased social responsibility (Han, Gao, & Shao, 2016; Kern et al., 2018; Kern et al., 2015).

Despite the critical role of design in RCWR, many designers are unwilling to integrate RCWR strategies into their designs (Wu et al., 2016). Hence, explicit RCWR objectives from clients can stimulate designers' motivation and give a sense of responsibility to conduct RCWR measures (Llatas & Osmani, 2016; Wu et al., 2016). The client-designer collaborative approach, combined with contractors' involvement in developing the waste management plan (WMP) during the design phase, can enable RCWR. Developing WMPs focusing on design and document management ensures precise and comprehensive information for construction and human resource management (Almusawi, Karim, & Ethaib, 2022).

Designing for standard material size improves economic performance and avoids material offcuts (Tu et al., 2023). 3DP technology has the potential to drastically reduce CW by enabling precise and efficient material usage (Tahmasebinia et al., 2018). In contrast to traditional methods, 3D printing uses only the material needed for the structure, resulting in less waste and a more sustainable construction approach (Zhang et al., 2019). Implementing 3D printing designs enables organising materials by size for easy identification and consistent utilisation based on construction methods and available space (Manrique et al., 2011). Designers should work with structural engineers to incorporate prefabricated structural components (Baldwin et al., 2009; Shooshtarian, Gurmu, & Sadick, 2023). Designers are expected to specify materials with recycling potential and use more durable construction materials to improve RCWR (Alqahtani, Sherif, & Ghanem, 2023; Estrada et al., 2023). The choice of materials in new construction can impact the end-of-life recycling rate of certain materials (Yang et al., 2022).

3.4.4 Contractor

Contractors are hired by the client to oversee and execute the construction process. The representation of the contractor’s role described in the literature ranks second highest after the designer's role, at 44% (see Figure 3.2). The contractor's role includes assigning subcontractors, purchasing materials, and ensuring adherence to regulations (Hassan et al., 2015; Mahamid, 2023). The contractor's involvement in the RCWR process starts with the planning and design. Lack of contractor involvement during design leads to increased rework and a significant increase in CW generation (Wang et al., 2020). Contractors can set economic incentives for designers to improve the quality of design execution (Tu et al., 2023). Managing CW generated from construction activities is a crucial responsibility of contractors (Lau, Whyte, & Law, 2008). The contractor often works closely with the project manager to improve onsite sorting practices, identify critical RCWR processes, and plan control strategies to help subcontractors implement RCWR (Bajad, 2022; Hao et al., 2019; Quiñones et al., 2022). When contractors and project managers fail to collaborate effectively, the RCWR process can be slower and more complicated (Katz & Baum, 2011).

The contractor contributes to RCWR by developing a WMP and adopting accurate CW estimation strategies (Mália et al., 2013). A precise CW estimation approach helps avoid budget overruns and increases economic benefits through RCWR (Hao et al., 2019; Lee, Kim, & Kim, 2016; Umar, Shafiq, & Isa, 2018). A WMP assists contractors in estimating the total quantity of CW by components during the planning phase, which can facilitate RCWR during construction (J. Li et al., 2013). Contractors are required to manage building materials and use adequate storage facilities to keep materials from damage (Poon et al., 2004; Quiñones et al., 2021). Project-related RCWR data must be accurately recorded by contractors during site auditing and measurements (Llatas & Osmani, 2016; Quiñones et al., 2021).

Environmentally aware contractors are mindful of RCWR throughout all stages of construction (Cao et al., 2015). However, financial risks often encourage contractors to prioritise earning maximum profits and meeting quality, cost and time requirements over considering environmental issues (Wu et al., 2016). Therefore, it is necessary to educate contractors about effective RCWR practices and the economic benefits of RCWR (Almusawi, Karim, & Ethaib, 2022; Braulio-Gonzalo, Jorge-Ortiz, & Bovea, 2022). Once contractors realise the economic benefits, they tend to increase their contribution to RCWR (Tu et al., 2023). Awareness and education help contractors adopt sustainable RCWR strategies by promoting positive attitudes towards RCWR activities and innovative technologies (Tatjana et al., 2021; Tu et al., 2023). The education should determine the degree of responsibility and interaction with each stakeholder to ensure high-quality outcomes.

According to Poon et al. (2004), RCWR procedures do not interfere with routine site activities or increase construction costs. However, contractors are willing to explore recycling options as long as recycling is feasible (Boser & El-Gafy, 2011). Integrating using recyclable materials and sharing resources during the commencement of residential building projects can lead to cost savings and reduced waste (Hao et al., 2019; Lee, Kim, & Kim, 2016). Large contractors are more likely to practice RCWR at construction sites than most contractors because of additional costs, lack of knowledge, and potential for regulatory non-compliance (Hassan et al., 2015; Pericot et al., 2014). Selecting the proper type of contract and introducing managerial policies aimed at RCWR can reduce material wastage by contractors (Mahpour, Alvanchi, & Mortaheb, 2019).

Contractors purchase construction materials based on design specifications and requirements, contributing to effective RCWR (Hao et al., 2021). Material surpluses result from procurement errors caused by miscommunication between the designer, contractor, and supplier (Bossink & Brouwers, 1996; Gavilan & Bernold, 1994). Surpluses often become waste due to inadequate consideration of reselling and storage options and the lack of material suppliers offering take-back schemes (Gavilan & Bernold, 1994). Contractors developing procurement systems with clear RCWR targets can achieve effective RCWR (Sassi, 2006). According to Pericot et al. (2014), higher recycling rates can be achieved by working with suppliers to take responsibility for waste and emphasising training and incentives among subcontractors.

3.4.5 Project manager

Project managers are hired by the client or the contractor, depending on the construction project delivery model, constituting 25% (see Figure 3.2) in the reported literature. The primary responsibility of project managers is to develop the WMP and closely monitor its implementation based on project priorities such as cost and time. The project manager can proactively identify potential waste-generation areas and take proactive measures (Lee, Kim, & Kim, 2016). The main challenges project managers face when relying on CW data for RCWR planning are the significant influences of material types and building design on generating various categories of CW at different construction stages (Maués et al., 2020; Tahmasebinia et al., 2020; Wang et al., 2020). Collaborating with designers and contractors and having access to data on CW supports project managers in developing effective RCWR strategies, which, in turn, enables contractors and subcontractors to avoid wasteful practices (Hassan et al., 2015; Poon et al., 2004). Project management should aim for sustainability, consider multiple areas of improvement, and prepare for continuous learning (Serpell & Alarcon, 1998). Project managers who participate in improvement processes tend to adopt continuous improvement as their management style (Serpell & Alarcon, 1998).

An effective WMP is expected to include identified recycling targets, waste removal contracts, monitoring procedures, and guidelines for onsite storage and source separation (Boser & El-Gafy, 2011). There is a growing emphasis on promoting WMPs to be given the same importance as other management plans within the industry. The WMP must consider all building life cycle phases, including closed and open-loop recycling potential (Treloar et al., 2003). A site WMP should be developed to state the procedures and commitments for RCWR. Auditing is required throughout the construction process, and a clear description of relevant roles and responsibilities must be recorded for assessment. Site-based waste management philosophy creates a culture of continuous improvements and innovative progress (Zhang, Eastham, & Bernold, 2005). A process- or site-oriented approach that defines the reduction of resource waste as the key objective is recommended (Wu et al., 2016).

A developed WMP should be flexible to allow for changes as the project progresses, as managing CW onsite may require additional labour, cost, and time (Maués et al., 2020; Sáez et al., 2014). Maximising the recycling rate of materials is best achieved through onsite sorting (Sáez et al., 2014). Comparatively, while prefabricated units are manufactured off-site, the transportation and installation of large and heavy components can lead to damage and generate some construction waste onsite (Hao et al., 2021). Thus, logistic factors in the WMP, such as transportation and handling processes, must be considered to optimise RCWR onsite.

Effective site management is crucial in RCWR, as illegal dumping and improper disposal undermine recycling efforts. Measures such as covering and securing CW containers and implementing fenced and locked project sites can help prevent illegal dumping but require significant supervision and monitoring (Boser & El-Gafy, 2011). Thus, conducting an audit for managing waste at the construction site is necessary during the construction stage. The audit is expected to record the name or job title of the relevant worker to be assessed (Wu et al., 2016). Facilitating waste sorting and recycling at construction sites enables responsible RCWR (Almusawi, Karim, & Ethaib, 2022; Han, Gao, & Shao, 2016). Additional consideration is required for lifting, storage, transport, and installation in high-rise building construction (Baldwin et al., 2008).

3.4.6 Subcontractor

The contractor hires subcontractors to perform specialised work onsite, such as tiling or electrical work (Katz & Baum, 2011; Mahayuddin & Pereira, 2014). The subcontractor's role primarily lies in onsite construction execution, with a 21% stake (see Figure. 11), indicating their contribution to RCWR. Subcontractors work under the contractor's supervision and may supply labour, equipment, and materials required to complete the assigned work (Hassan et al., 2015). The contractor must employ qualified subcontractors during the planning phase to proactively reduce the occurrence of wasteful practices (Shooshtarian, Gurmu, & Sadick, 2023). However, the subcontractors' contribution to RCWR starts during construction and continues until the work is completed.

The actions of subcontractors influence and significantly contribute to onsite RCWR practices (Gavilan & Bernold, 1994). Data availability, regulation, monitoring of RCWR procedures, and better communication between the contractor and subcontractors optimise subcontractors' contribution to RCWR (Ferronato et al., 2023; Gavilan & Bernold, 1994). For example, in the case presented by (Poon et al., 2004), subcontractors are continuously monitored onsite and reminded of the duties specified in the WMP. The harsh environmental conditions on the construction site, coupled with the physically and mentally demanding nature of the work, are further complications for RCWR (Hassan et al., 2015). Therefore, enforcing strict measures could result in labour resistance and pose challenges to project completion (Hassan et al., 2015). J. Li et al. (2013) argued that the worker's performance is less likely to improve when there is a lack of awareness about the environmental aspect. Nevertheless, the contractor must instruct the subcontractors on onsite sorting and RCWR practices (Poon et al., 2004). Providing training on RCWR procedures and performance incentives to subcontractors throughout the construction process is necessary to enhance their contribution to RCWR (Pericot et al., 2014; Poon et al., 2004).

Residential construction sites often have multiple subcontractors working onsite at the same time, in different trades, which have the potential to generate various levels of waste, complicate RCWR activities, and make the identification of the responsible party for the waste generated from each work trade difficult (Mahayuddin & Pereira, 2014; Umar, Shafiq, & Isa, 2018). Therefore, it is necessary to specify subcontractors' RCWR responsibility and accountability when preparing contracts. Contractual agreements with subcontractors can include requirements that limit the amount of CW they can generate, mandate the purchase and disposal of materials, and include penalty and bonus clauses for losses above or below the waste limit (Poon et al., 2004). The conditions encourage contractors to use skilled labour and maintain an effective supervision system, and subcontractors to handle materials appropriately and be environmentally aware (Hassan et al., 2015; Poon et al., 2004).

3.4.7 RCWR services provider

The primary role of RCWR service providers is to collect, sort, and transport waste for diversion, ultimately reducing environmental impact and promoting sustainability (Lau, Whyte, & Law, 2008; Sassi, 2006). Diversion facilities include equipment and a location for collecting, storing, and sorting waste off-site (Mahayuddin & Pereira, 2014). Other RCWR services, such as green rating schemes, might involve construction process management and waste process standardisation (Cao et al., 2015; Mahpour, Alvanchi, & Mortaheb, 2019). These service providers are expected to introduce innovative technologies to boost waste recycling and reusing rates in RCWR systems (Alqahtani, Sherif, & Ghanem, 2023; Arora et al., 2020). Moreover, there is a drive for research on using recycled materials to assess their impact on environmental sustainability and facilitate better decision-making in the design and material selection for new construction (Mahpour, Alvanchi, & Mortaheb, 2019). Initiating a discussion with RCWR service providers during design, planning, and construction about the types of material wastes, potential recyclers, the required quality, handling considerations, volume, and cost of recycling services facilitates connection and collaboration for efficient RCWR (Almusawi, Karim, & Ethaib, 2022; Boser & El-Gafy, 2011).

The shift towards recycling is driven by cost savings rather than the intrinsic value of materials and RCWR benefits. The RCWR services system requires substantial investments and operational costs (Cao et al., 2015; Ferronato et al., 2023). However, integrating waste recycling and reusing practices into the RCWR services system presents financial and logistical challenges (Boser & El-Gafy, 2011; Estrada et al., 2023). Yet, it can also serve as a valuable source of revenue (Ferronato et al., 2023). RCWR service providers represent 17% of the literature (see Figure 3.2) and are typically private investors with contractual agreements (Lau, Whyte, & Law, 2008). Strategies such as public participation, education, and incentives are recommended to optimise RCWR systems (Boser & El-Gafy, 2011; Estrada et al., 2023).

3.4.8 Supplier

Material suppliers are typically hired by the contractor. The supplier's representation in the literature is 36% (see Figure 3.2), underscoring their crucial contribution to the material supply. Suppliers are responsible for reducing the excessive packaging of materials and providing clear instructions on installing and storing the materials. This can ultimately save resources and reduce costs for the supplier and the client. Suppliers play an essential role in providing detailed information about the materials, including environmental information, during the lifecycle of their products (Quiñones et al., 2021). Standardised product LCA encourages competition among suppliers and contractors to create and utilise eco-friendly products with Environmental Product Declarations (EPDs) (Padilla-Rivera, Amor, & Blanchet, 2018). Products with EPDs are valued by the construction sector, leading to environmentally low-impact residential construction through energy and material efficiency (Padilla-Rivera, Amor, & Blanchet, 2018).

Manufacturing industries should be aware of the need to lower their resource consumption, including embodied energy, to reduce waste in upstream processes (Treloar et al., 2003). Waste in upstream processes may have a more substantial impact than that resulting directly from the construction process (Treloar et al., 2003). The transformation involves incorporating resource efficiency, clean technologies, and sustainable design into manufacturing processes and investing in green infrastructure (Lehmann, 2012).

There is an increasing recognition of prefabricated residential building components to achieve the RCWR. Achieving RCWR is attributed to the critical nature of the design process in building materials and components (Llatas & Osmani, 2016). For instance, Atta, Bakhoum and Marzouk (2021) indicated that prefabricated elements and demountable connections play a significant role in the pre-eminence of modular building alternatives. Prefabricated residential construction achieved higher RCWR rates compared to traditional construction due to better quality control in the manufacturing process (Cao et al., 2015). Implementing a high degree of prefabrication has high-quality finishes, reduces raw material consumption, enables efficient recycling, and decreases the CW and emissions at the site (Cao et al., 2015; Wallhagen & Glaumann, 2011). Material suppliers communicate with designers to optimise the architectural geometry for fabrication using digitisation tools to enhance the manufacturing process and RCWR efficiency (Rausch, Sanchez, & Haas, 2021).

Awareness about the efficient use of materials with RCWR value enhances successful implementation while maintaining cost competitiveness (Mullens & Arif, 2006). Considering the choice of materials with RCWR value, attention should be paid to materials recycling and developing energy-efficient construction technology (Sánchez Cordero, Gómez Melgar, & Andújar Márquez, 2019). Materials that are not excessively packaged and follow the supplier's instructions for handling, transporting, and storage are recommended. Additionally, it is advisable to consider engaging with suppliers with measures to manage their product waste, as this can be an effective strategy for choosing suitable materials (Sáez et al., 2014).

Material suppliers' efforts to RCWR should focus on energy-efficient construction technology and green production. Green construction materials should be evaluated comprehensively before practical application (Wei et al., 2017). Green construction materials may be controversial due to new types of materials or faster deterioration with second-use ingredients, so it is essential to evaluate these factors comprehensively and from a long-term perspective before practical application (Yan, Lai, & Lin, 2012; Zhang et al., 2023). Contractors explore the market of recyclable materials and find potential suppliers interested in acquiring the raw material (Ferronato et al., 2023). The supplier's interest in RCWR could benefit the development and expansion of their product market.

3.4.9 Regulator

With a 40% stake (see Figure 3.2), the regulator wields significant control over the RCWR's compliance with regulations, accentuating their substantial contribution to bolstering the responsibility and accountability in the RCWR process. The regulator represents the national and local government authorities responsible for enacting RCWR policies and monitoring compliance in the RCWR process. The role of regulation is to control and standardise RCWR in an environmentally responsible manner from design to construction completion (Mercader-Moyano & Ramírez-de-Arellano-Agudo, 2013). Regulations include enacting building codes, standardising materials, imposing taxes on CW generators, setting WMP targets and CW diversion requirements, and applying incentives and rewards. Regulators are responsible for setting recycling targets and guiding the construction industry by setting indicators to increase recycling rates (Sánchez Cordero, Gómez Melgar, & Andújar Márquez, 2019; Yang et al., 2021).

Furthermore, regulators can develop targeted measures to promote sustainable practices by improving CW data quality, evaluating circular economy strategies, conducting LCAs, and encouraging research (Shen, Yang, & Yan, 2023). Some of these policies include promoting BIM implementation, incentivising RCWR, planning new taxes for CW generators, and implementing reward-based programs (Ferronato et al., 2023; Mahpour, Alvanchi, & Mortaheb, 2019). Taxes and fees charged to CW should be reasonable to achieve maximum effectiveness in RCWR (Hao et al., 2019).

Establishing policies and regulations for RCWR involves promoting sustainable construction practices, enhancing onsite sorting, and encouraging innovative waste reduction and recycling technologies (Almusawi, Karim, & Ethaib, 2022; Cochran et al., 2007). For instance, legislation is essential for introducing incentives to innovative design and construction processes, including BIM (Georgiadou, 2019). Legislation and incentives can enhance RCWR while regulating new technologies to ensure optimal use (Tang et al., 2021). Appropriate norms and laws should be considered when regulations of new technologies are developed (Ferronato et al., 2023). In addition, regulatory authorities must ensure adequate enforcement and monitoring of RCWR regulations (Boser & El-Gafy, 2011). National policies and regulations for preparing WMPs can help governments facilitate an integrated RCWR (Zhang et al., 2023).

Regulations drive the construction industry to develop alternatives to RCWR systems (Lehmann, 2012). Therefore, policies and laws should increase awareness and promote knowledge about RCWR practices (Hassan et al., 2015). Governments must distinguish between waste and reusable materials (Arora et al., 2020). Regulation that addresses RCWR should be comprehensive and consider the entire lifecycle of a construction project - from the design and construction phase to the usage phase and even the demolition phase (Jingkuang, Yousong, & Yiyong, 2012). A policy framework that addresses the variance in building types and project sizes will effectively maximise RCWR (Georgiadou, 2019).

Regulators have an educational role in increasing the participation of other stakeholder groups by learning the benefits and value of participating in RCWR. Government authorities may provide guidelines about the correct handling and storing of potentially reusable or recyclable materials to contractors (Poon et al., 2004). Regulations support the efficiency of a WMP by mandating reporting on CW quantities, which is necessary for site-specific project management and waste planning (Sáez, Porras-Amores, & del Río Merino, 2015). The lack of regulatory support for onsite WMPs substantially impacts CW generation. Considerations in regulating WMP must encompass the assessment of market demand for recycled materials, logistics and transportation factors, sorting and cost management challenges, and the risk of contamination in mixed materials (Almusawi, Karim, & Ethaib, 2022). Developing standardised onsite waste management procedures can promote the reuse and recycling of material waste. Yet, high turnover rates, costs, and training may limit successful implementation (Cao et al., 2015).

3.5 Conceptual Model Development

Based on the SLR, Figure 3.3 proposes a conceptual model of stakeholders' interactions and contributions to RCWR. The model comprises the stakeholders' roles and showcases their interactions and contributions to RCWR. Through investing in RCWR, the client plays a pivotal role in driving the initiation and enhancement of RCWR strategies, particularly during the design and planning stage. The client's financial commitment often sets the tone for the project's sustainability goals, influencing the resources allocated to sustainable practices and technologies.

As the project progresses, each stakeholder must understand their role in the collective effort to educate and raise awareness about the benefits of RCWR. This shared responsibility enhances stakeholders' commitment and fosters potential collaborative efforts, making each stakeholder feel valued and integral to the project's success (Larsson & Larsson, 2020). The regulator, represented by government officials, plays a central role in providing information about the best RCWR practices through successful showcases in government-led housing projects. The regulator's role also extends to enhancing data collection and managing reporting and monitoring of RCWR performance indicators. Regional-level benchmarking is also required as more regions increase recycling and reduce landfill disposal. The development of the WMP is a critical collaborative RCWR strategy in the design and planning stage. The availability of waste data maximises the efficiency of WMP (Shooshtarian, Maqsood, et al., 2022). Collaboration between the contractor, designer, project manager, and RCWR services provider is crucial in implementing various RCWR strategies and integrating technologies to optimise RCWR through the construction process.

The contractor's and project manager's influence on RCWR extends to project completion. The contractor's primary responsibility is establishing effective communication with the suppliers, starting from the design and planning phase through the construction process. This communication is necessary to ensure that the installation and storage guidelines for the materials are well understood and followed. The contractor's interaction with suppliers includes understanding EPDs and defining product waste responsibility, a crucial RCWR strategy. On the other hand, subcontractors play a significant role in implementing onsite RCWR strategies like waste sorting.

Waste sorting practices can improve recycling and reusing through RCWR services providers with a private contractor’s agreement for RCWR. Contractors and project managers have a role in promoting cooperation with RCWR service providers to plan and standardise the RCWR process and overcome onsite management limitations. It is important to note that while the contractor and project manager may have similar roles, the project manager takes on the onsite supervision role. In contrast, the contractor holds the contractual responsibility (Anyanwu, 2013). Clarity about their roles is essential to ensuring effective RCWR compliance within the project's time and budget.

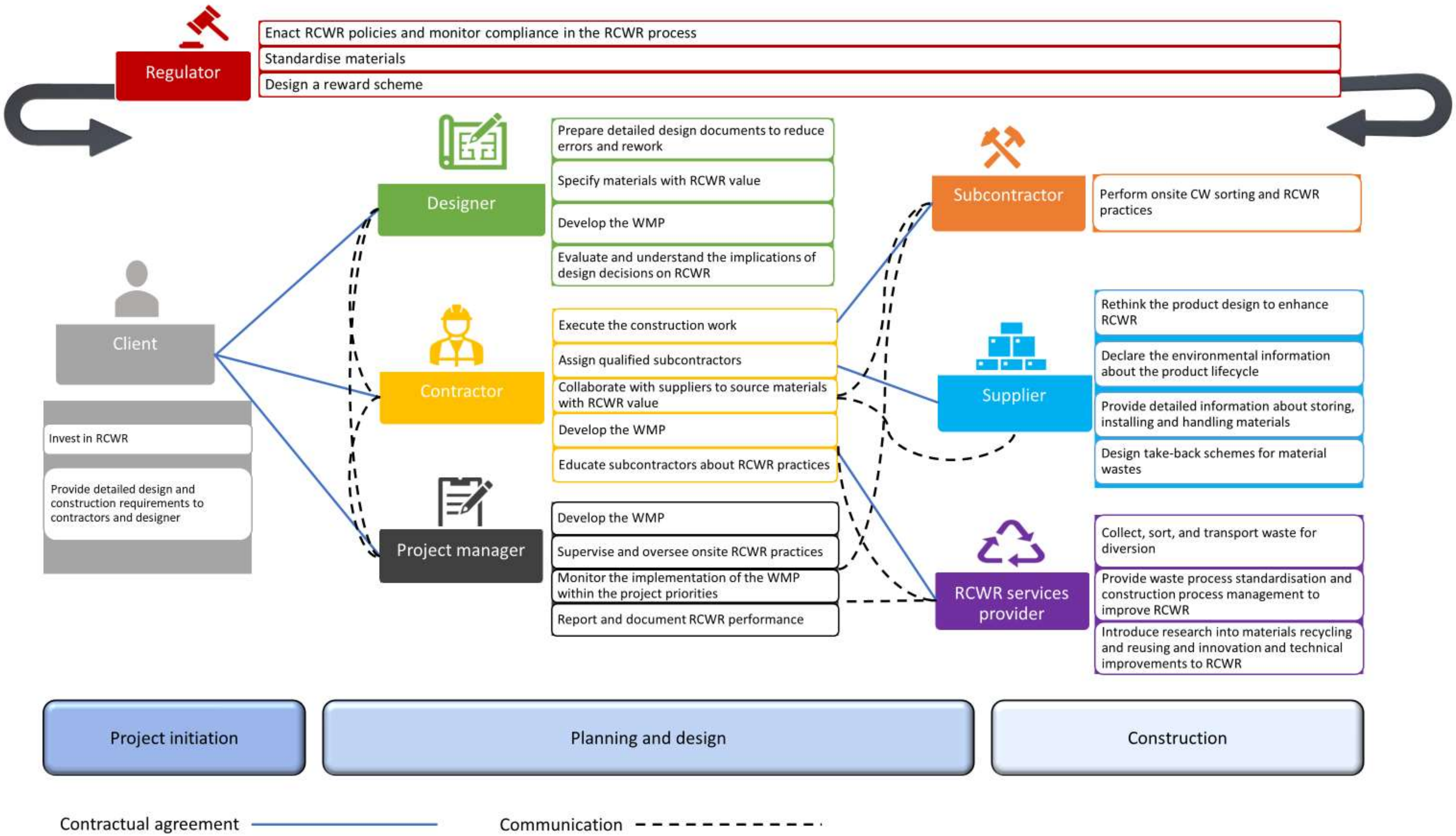

Figure 3.3: A conceptual model of stakeholders' interactions and contributions in RCWR

3.6 Recommendations and Future Directions for New Zealand

RCWR is crucial for achieving sustainability and a circular economy in New Zealand's construction sector. This review demonstrates the necessity for the built environment to embrace a broader range of RCWR strategies to optimise the benefits derived from RCWR. Recommendations related to the timing and duration of implementation and scope of improvement can be classified into short-term and long-term categories. Short-term recommendations are based on easily achievable improvement opportunities requiring low effort and economic investment. On the other hand, long-term recommendations require a considerable amount of development effort and a more extended implementation period. A summary is listed in Figure 3.4.

3.6.1 Short-term recommendations

The construction industry in New Zealand should take an educational and process-focused approach to improve RCWR. This involves comprehensive project planning, training programs, design for RCWR, clear RCWR scope, and an efficient procurement system (Rahman et al., 2021). The industry should prioritise quality site management planning, facilitate communication among interconnected stakeholders, and consider factors influencing RCWR (De Magalhães, Danilevicz, & Saurin, 2017). The residential sector in New Zealand could benefit from short-term action in education to enhance regulatory compliance and encourage the achievement of a circular economy and RCWR. Education is the most critical factor in generating attitudinal and behavioural change among stakeholders to move towards effective waste management (Shooshtarian, Caldera, et al., 2022).

Making minor adjustments to current procurement practices and data collection on CW can significantly enhance the construction process by integrating automated systems and prioritising products with an environmental declaration. Numerous opportunities for improvement can be achieved through such short-term actions. Collaborating with construction industry associations and organisations to establish industry-wide RCWR standards and best practices is recommended. The construction industry in New Zealand has collaborated with the government to improve productivity, innovation, and efficiency. Regular meetings between industry leaders and government decision-makers are essential to drive innovation and improve business performance (Adafin et al., 2022).

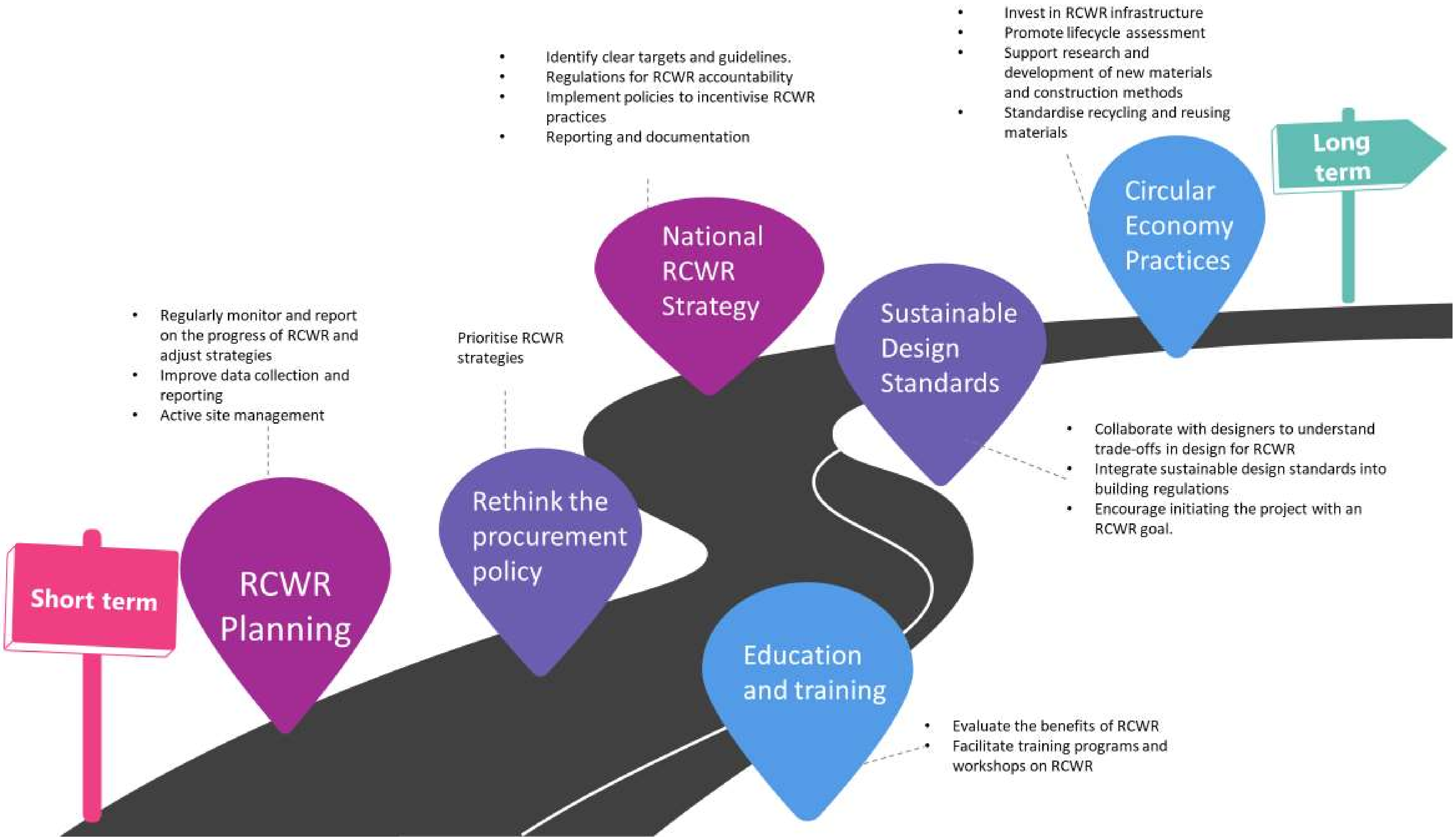

Figure 3.4: Recommendations for future direction in RCWR in New Zealand

3.6.2 Long-term recommendations

Implementing long-term recommendations is crucial to optimising RCWR and ensuring a sustainable and resilient residential built environment. Long-term actions often entail significant changes that may yield observed benefits after some time. Such actions necessitate substantial development efforts and a more protracted implementation cost and timeframe. A business model that considers RCWR in residential materials and components supply and facilitates shifting to circular construction can make developing a market for recyclable and green construction materials easier, maximising RCWR benefits. Thus, creating value from material wastes that offsets the cost of waste management operations and RCWR services.

These actions involve implementing a national RCWR strategy. While the national waste strategy in New Zealand (Ministry for the Environment- MfE, 2023b) is a significant step forward in addressing the challenge of waste management, but some gaps still need to be addressed. One of the gaps is the need for defined measurable targets for RCWR. The strategy sets out general objectives and actions but needs concrete targets to measure progress towards RCWR goals. Another gap is the need for clear guidelines for reducing the use of materials with high waste profiles, such as timber, which significantly contributes to the CW stream.

As design is a critical phase in the decision-making process for RCWR, enhancing design for waste reduction may be beneficial to consider introducing innovative construction methods that prioritise RCWR. Additionally, expanding the accessibility of waste management infrastructure can help facilitate recycling and waste sorting at construction sites (Ahmed & Zhang, 2021). Designers and regulators are crucial in promoting waste reduction in construction projects. Designers can incorporate innovative construction methods that prioritise RCWR into the design. At the same time, regulators set design standards and regulations and provide incentives for design compliance, creating an industry culture for RCWR. Moreover, funding research and innovation in RCWR, such as developing new technologies and products that support the shift towards circular construction (Adafin et al., 2022).

3.7 Conclusions

The residential construction industry is proliferating, resulting in increased CW. The impacts of CW are evident, requiring a collaborative effort for efficient RCWR action. A comprehensive understanding of the stakeholders in RCWR clarifies and enhances their roles and contributions. Therefore, our study has systematically identified and analysed seven prominent stakeholder roles in RCWR: the client, contractor, designer, project manager, supplier, subcontractor, and regulator. A conceptual model has been proposed to showcase the interactions and contributions of stakeholders involved in RCWR. The findings highlight key strategies to enhance stakeholders' contribution to RCWR, emphasising education on best practices and awareness of RCWR benefits in fostering commitment and collective work.

The client takes the role of an investor in RCWR, which enhances the commitment of the contractor, project manager, and designer to RCWR. The client's interaction with the designer and contractor about the project requirements helps with the design and planning for RCWR. The designer is primarily responsible for standardising the design and specifying materials to improve RCWR. The designer, project manager, and contractor must collaborate to develop an efficient WMP within the project's priorities. The contractor's decisions on suppliers and subcontractors' selection significantly influence the efficiency of RCWR. Prioritising suppliers who take responsibility for their product's waste, providing EPDs and reporting on the CW operations enhances RCWR. Subcontractors help with on-site waste management, particularly waste sorting, while project managers oversee the process. RCWR services work to improve waste reduction throughout the construction process by following the client's and contractor's directions, which involves planning to enhance RCWR and providing solutions such as reusing and recycling. The RCWR process is overseen by the regulator, impacting all stakeholders to ensure compliance.

Despite conducting a comprehensive SLR, relevant studies may be missed due to keyword search and inclusion/exclusion criteria. Future research potential using interviews, document analysis, and mapping techniques is promising. Multiple factors can influence the RCWR process, and a dynamic view of the system is essential. Investigating factors influencing RCWR using primary data can help build a decision-making model to enhance stakeholder integration. This study provides a comprehensive understanding of each stakeholder's contributions to the RCWR process. The study improves knowledge in this field and presents a guide for future and current RCWR policymaking, sparking interest in the ongoing development of RCWR.

Chapter 4 Factors Influencing Residential Construction Waste Reduction: A Qualitative Investigation in New Zealand.

4.1 Prelude

This research paper explores the perspectives of key stakeholders identified in residential construction waste reduction (RCWR), as identified in chapter three. The aim of this research is to investigate the factors influencing RCWR in New Zealand. The research design followed a qualitative semi-structured interview approach and recruited RCWR relevant participants. The findings revealed eight categories of factors: operational, governance, economic, innovative and technical, social and behavioural, environmental, process and procedures, and organisational. The findings reveal that these factors are interconnected and critical to achieving effective RCWR. This research offers valuable insights into the multifaceted nature of factors influencing RCWR. The findings inform policymakers, construction practitioners, and waste management professionals in making informed decisions and implementing targeted interventions for sustainable RCWR practices. The results also provide a foundation for future quantitative research to evaluate and explore the dynamics of these factors further. Ultimately, this research contributes to developing effective RCWR strategies and proactive decision-making in the residential construction sector.

4.2 Introduction

The global rise in CW generation is primarily due to accelerated urbanisation rates (Yazdani et al., 2021). Urbanisation requires accommodating the rising demand for residential construction driven by population growth. Most construction in New Zealand is for residential dwellings, accounting for 88% of new buildings by quantity, 75% by value, and 71% by floor area, generating the primary source of CW (Nelson et al., 2022). In addition, recent urban development in New Zealand, mainly Auckland, has significantly increased CW disposed to landfills. Disposing of CW in landfills leads to the depletion of valuable materials (Sahlol et al., 2021) and threatens social, economic, and environmental sustainability (Hernandez et al., 2023).

CW reduction has received significant focus in New Zealand and other countries undergoing large-scale developments due to the recognition of the extensive impacts of CW (Albsoul et al., 2024c; Ma et al., 2020). For instance, the European Commission has promoted circular economy practices and reinforced a set of targets to enhance the quality and quantity of CW recycling outcomes (Abu-Bakar et al., 2023). Similarly, China and the US have implemented advanced construction technology and proposed regulations and policy interventions to optimise CW management efficiency (Aslam, Huang,

& Cui, 2020). Some countries, such as the UK and Germany, have achieved landfill rates that are near zero, while others, like China and Brazil, have yet to achieve sufficient CW reduction progress (Bao & Lu, 2020). Consequently, the effectiveness of CW reduction strategies differs due to varying economic, regulatory, and cultural characteristics, highlighting the necessity of understanding CW reduction at the national level and customising waste management strategies accordingly (Aslam, Huang, & Cui, 2020; Duan et al., 2019).

Therefore, this research aims to investigate the factors influencing RCWR by exploring stakeholders' perspectives in New Zealand. Investigating RCWR within New Zealand's residential sector offers valuable contributions to global insights by exploring the distinctive nature of implementing RCWR in a unique regulatory framework characterised by a relatively small economy compared to the US, UK, and China. The need for this investigation arises from the critical role of the residential construction sector in the global demand for construction materials, resources, and energy consumption (Deetman et al., 2020). According to the New Zealand's waste strategy (Ministry for the Environment- MfE, 2023b), the construction industry needs to focus on creating data sources, setting goals, and improving practices related to waste reduction. However, research has shown that various factors can influence the efficiency of waste reduction in construction (Liu, Yi, & Wang, 2020). Understanding the factors influencing RCWR is valuable in developing conceptual models and decision-making frameworks that inform performance-based practices.

In contrast to previous research that addresses construction and demolition waste management on a global or national scale, this research specifically investigates CW arising from the initiation until the completion of the residential project. This focus on residential construction is driven by the pressing need for a sustainable model to address the challenges posed by urbanisation, economic growth, and the environmental consequences associated with the substantial consumption of materials and waste generated. Additionally, the research incorporates a qualitative approach to help identify areas for optimising RCWR, tailor RCWR practices, and facilitate the move to circular management. This study is based on interviews with subject matter experts involved in RCWR in New Zealand to provide a comprehensive empirical perspective. Research outcomes will assist decision-makers in formulating strategies for RCWR, promoting the growth of a circular economy, and yielding empirical data to serve as a reference point for future research endeavours.

4.3 Literature Review

Researchers have investigated the factors influencing CW reduction using diverse investigative and analytical methods. One focal area is CW reduction during the design phase. For example, Wang, Li and Tam (2014) revealed that factors influencing waste reduction in design include incorporating prefabrication and modularity, design alterations, incentives, and investing in waste reduction. Using prefabricated components, professional training, and robust policies promotes and reduces CW during design (Yuan et al., 2022). Further exploration into the design phase revealed that social and market factors have a significant influence on design units' willingness to reduce CW, followed by government oversight and designer attitudes (Wang, Yu, et al., 2019). Project constraints such as time and cost have minimal impact, while internal company culture indirectly influences the willingness for CW reduction(Wang, Yu, et al., 2019). A comprehensive study by Daoud, Othman, et al. (2023) acknowledged that implementing efficient practices, legislation, cultural and behavioural changes, and increased awareness effectively reduced CW in Egypt.

The literature underscores the significance of source planning and incentive policies in CW reduction. According to Liu, Yi and Wang (2020), waste management behaviour incentivised by policies and the transportation of building materials in the source plan are crucial factors influencing CW reduction. Moreover, strategies such as improving CW sorting practices, curbing illegal dumping, advocating for government subsidies for waste recycling, and raising waste landfilling charges can enhance the economic performance of CW reduction (Hao et al., 2019). Furthermore, the availability of human resources, a market for recycled materials, waste segregation, improved management practices, sufficient site space, and appropriate sorting equipment are crucial for facilitating onsite sorting and successful CW reduction (Wang et al., 2010).

In the realm of behaviour, studies have shown that "knowledge" significantly influences CW reduction behaviour. Contractor training programs, stricter regulations, and public awareness are suggested as potential interventions to enhance CW reduction behaviour (X. Li et al., 2018). Additionally, the deliberate intention of contractors to reduce CW, government monitoring, economic incentives, and perceived behavioural control are noted as influential factors in contractors' actual CW reduction behaviour (Li et al., 2022). The proactive commitment of contractors to reducing CW was highlighted as essential for efficient reduction (Li et al., 2022). Moreover, Bakshan et al. (2017) classified the factors influencing workers' behaviour in CW management into personal (attitude towards waste management, awareness of consequences, work experience, experience with waste management, and social pressure) and corporate (training, supervision, and financial incentives).

Table 4.1 provides an overview of research methods employed to investigate the factors influencing CW reduction in various contexts. However, there exists a notable gap in the research focused exclusively on the residential sector. Particularly in New Zealand, investigating factors influencing

RCWR lacks empirical data, creating an opportunity for inquiry in this area. Furthermore, current studies mainly rely on quantitative methods, emphasising the necessity for qualitative empirical data. Incorporating empirical data would provide a more comprehensive and in-depth understanding of the factors at play and their interconnections.

Table 4.1: Summary of research methods and context of factors influencing CW reduction

Reference	Research method	Investigated factors
Wang, Li and Tam (2014)	Quantitative survey questionnaire	Design
Daoud, Othman, et al. (2023)	Quantitative survey questionnaire	Materials procurement, legislation, awareness, culture, and behaviour, green building practices
Liu, Yi and Wang (2020)	Quantitative survey questionnaire	Source plan and incentive policies
Hao et al. (2019)	Qualitative site interviews	Economic performance of CW reduction
X. Li et al. (2018)	Quantitative survey questionnaire	Contractor's behaviour
Li et al. (2022)	Quantitative survey questionnaire	Contractor's behaviour
Wang et al. (2010)	Quantitative survey questionnaire Qualitative interviews	Onsite sorting
Wang, Yu, et al. (2019)	Quantitative survey questionnaire Qualitative interviews	Design
Yuan et al. (2022)	Case study	Design
Bakshan et al. (2017)	Site Quantitative survey and interviews	Site workers' behaviour

4.4 Method

This study aims to investigate the factors influencing RCWR; therefore, the qualitative design of semi-structured interviews will be used to gather input from subject matter experts in RCWR in New Zealand. Figure 4.1 illustrates the design of the method.

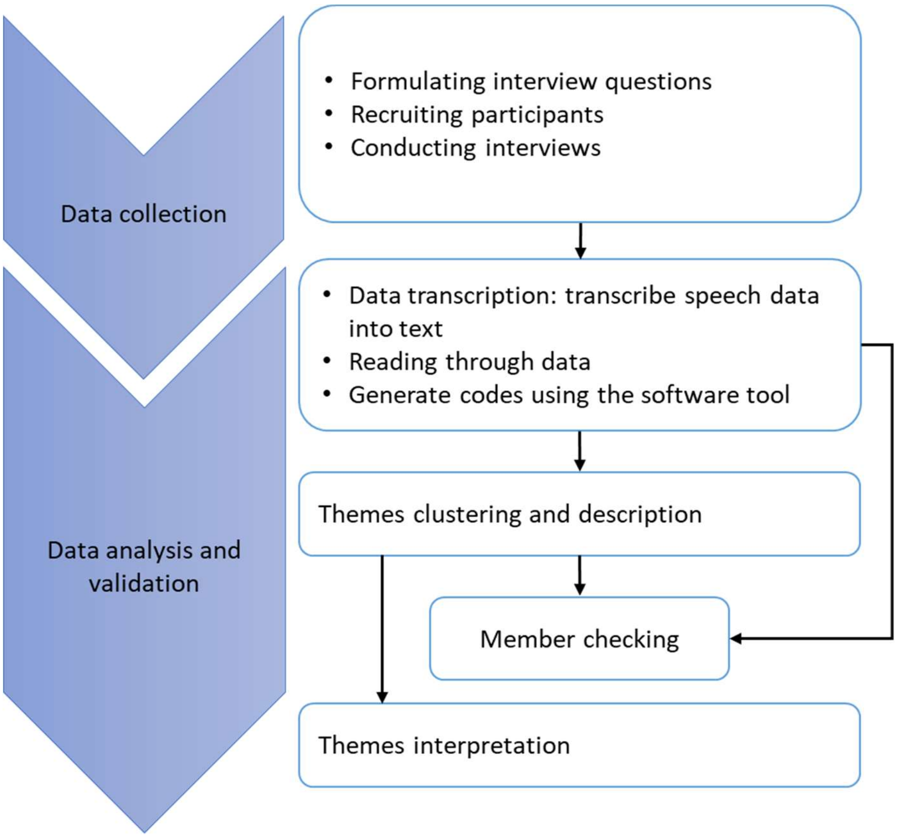

Figure 4.1: Methodology flowchart (Creswell, 2017)

4.4.1 Data collection

In-depth interviewing is a technique to delve into views and perspectives concerning a specific concept or state of interest (Morris, 2015). For this research, the interviews follow a semi-structured design with predetermined questions. The questions are designed based on pre-identified themes that allow interposition to pursue more clarifications. The conversation begins with a focus on a particular area and continues to develop as more questions emerge (DeJonckheere & Vaughn, 2019). The selected sampling technique is purposeful sampling followed by snowball sampling. To ensure relevant and reliable qualitative data, interviewees should have: i) experience in the residential construction sector in New Zealand; ii) a dynamic role relevant to RCWR; iii) a minimum overall experience of three years.

Generally, the sample size is sufficient when data saturation is accomplished (Dworkin, 2012; Suri, 2011). A basic definition for data saturation is when no more insights are sparked from data collection (Dworkin, 2012). Interview settings were designed to be face-to-face and online via internet platforms like Microsoft Teams. The face-to-face interview setting benefits researchers and participants by allowing more people to participate, growing networks, and providing comfort to encourage morally diligent answers (Schober, 2018). Alternatively, Internet interviewing has the advantage of time and location flexibility for both the researcher and the participant (Hanna, 2012).

4.4.2 Data analysis and validation

Initially, recorded dialogues are transcribed from speech to text. The transcripts are sent to each participant to determine and check for accuracy (Creswell, 2017). Member check seeks to resonate results with the participants' subjective experiences (Birt et al., 2016). Then, the data are reviewed and coded. The data is expected to be dense and abundantly informative. Hence, a data procedure called 'winnow' is performed (Creswell, 2017). This procedure clusters data into themes.

The software tool 'NVivo' is used for theme coding to organise and analyse the in-text information by ordering and categorising it (Creswell, 2017). NVivo has key features as an analysis tool, such as fitting the abundance of information and supporting time efficiency and data transparency (Dollah, Abduh, & Rosmaladewi, 2017). Eventually, it is necessary to implement reliability procedures following the steps that Creswell (2017) suggested. The first step is to reread the transcripts and ensure there are no errors through transcription. The second step is to ensure codes are clearly defined to eliminate any drift in the meaning of codes.

4.5 Results

4.5.1 Participants characteristics

A total of 15 participants were recruited from different stakeholder groups from November 2022 to March 2023. In qualitative research, a typical guideline for sample size is 15 ± 10 (Hurlimann et al., 2018). Previously reviewed studies in this field have been published with comparable sample sizes in a qualitative design. The study aimed to include participants who have a crucial role in designing and implementing strategies and policies in RCWR, such as government officials, sustainability consultants, and residential construction professionals. The sample size was sufficiently diverse in terms of background and experience. All participants were employed in permanent jobs, with 14 working full-time and one working part-time at the time of their interviews. The participant cohort consisted of government officials (n=3), sustainability and waste professionals (n=5), construction industry practitioners (n=5), and construction sustainability research and advisory experts (n=2). Most participants (n=14) were based in Auckland, while one in Wellington. Three participants were involved in regional projects around New Zealand. Additionally, several participants (n=4) had an experience overseas, particularly in Australia, Europe, and the US. Figure 4.2 summarises the participants' characteristics.

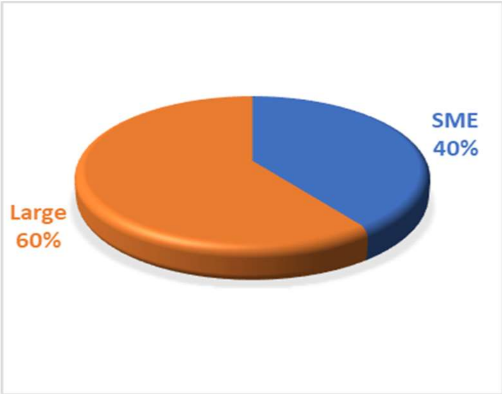

Figure 4.2.a: Size of Company

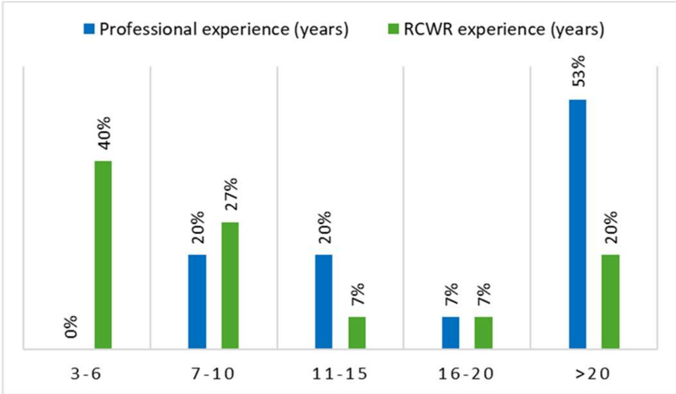

Figure 4.2.b: Participant's experience (years)

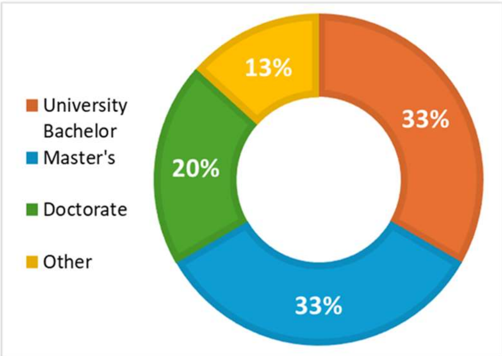

Figure 4.2.c: Highest Degree

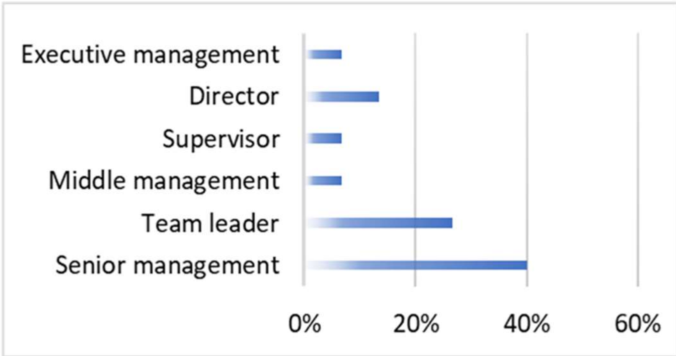

Figure 4.2.d: Organisational portfolio

Figure 4.2: Participant's characteristics

4.5.2 Operational factors

4.5.2.1 Design optimisation

All participants agreed that RCWR starts from the design and planning stage, see Table 4.2. As **P2** stated, "*If you don't plan to reduce waste, there will not be less waste. If the intention is there, then that will go to the whole process*". Designing out waste allows for greater control over decisions for RCWR, such as the choice of material without significant cost. According to **P4**, "*there is an opportunity for architects and designers to specify materials with better environmental outcomes*". However, the focus on environmentally preferable materials and RCWR in architectural practices is still limited.

The fundamental strategy in designing for RCWR is to collaborate closely with designers and establish a strong connection with the builder. As **P12** pointed out, "*Designers might be unaware of the amount of waste that is a consequence of the choice they've made. Making sure they have a better understanding of consequences and what options they have in front of them would be the priority*". From the perspective of architects, RCWR may be overshadowed by other concerns and responsibilities in their projects, as the design should allow for material options that align with the client's desired aesthetic and design freedom. Additionally, designers may not feel the same level of pressure as contractors unless the client demands explicitly RCWR.

The diversity in residential design in New Zealand is hindering the progress in RCWR. According to **P13**, "*We're quite wasteful as a sector with how we design*". The customisation and construction of bespoke houses result in waste generation. Non-standard dimensions and custom requirements often lead to material wastage and inefficiencies due to the inevitable occurrence of off-cuts. Designers may select materials with specifications that differ from what is available. As a result, builders need to cut these materials to fit, leading to off-cut waste. Even in cases where bespoke designs are still preferred, interventions with designers are necessary to enhance their understanding of standard material sizes and how to design homes that generate less waste from the start. Suggested strategies are engaging designers to adjust the design dimensions, working with manufacturers to produce materials that align with specific project requirements, increasing awareness about standard specifications for materials in design, and slightly adjusting the house's size can prevent unnecessary waste.

These findings align with existing research emphasising the impact of design choices on RCWR (Wang, Li, & Tam, 2014; Wang et al., 2019a; Yuan et al., 2022). During the design phase, optimising material and component dimensions is essential to design waste out (Wang, Li, & Tam, 2015). Studies conducted in the UK (Ajayi, Oyedele, Akinade, Bilal, Alaka, et al., 2017) suggest specific measures to be taken during project planning and design. A waste-efficient design strategy includes standardisation and dimensional coordination, the application of modern construction methods, provisions for end-of-life deconstruction, and optimising design coordination (Llatas & Osmani, 2016).

4.5.2.2 Logistics and infrastructure

All participants recognised the vast influence of logistics and infrastructure in RCWR, regardless of participant characteristics (see Table 4.2). As **P3** emphasised, "*Logistics is a massive problem. Infrastructure is not there. There are services that are not there, and if they are, it is expensive*". Concerns about transportation challenges highlighted combining separated items from different sites to a landfill instead of recycling facilities. According to **P13**, "*If you did manage to separate, the waste removal trucks come along and put it all back together and stuck it all in the same truck, which is very demoralising*".

Some participants added that transporting waste materials over long distances is a major constraint, especially for rural, smaller population regions, adding to costs and carbon emissions. Another limitation is the need for secure places protected from environmental degradation to store materials for reuse. **P7** stated, "*You got a lot of material becoming available, but you need to put it somewhere*". Onsite storage space is a concern, and offsite storage requires transportation, maintenance, and additional logistics. Further concerns are the storage cost, size of large items, and projected carbon footprint of material reuse and recovery.

A standard view amongst participants was regarding regional variations in infrastructure capacity, accessibility, and availability. Due to population size, residential construction volume, and economic capacity, Auckland benefits from more infrastructure, including recycling plants and waste centres. The role of local councils in leading construction companies was emphasised by providing waste management information tailored to each region. Strategies such as stockpiling, reverse logistics, and proactive planning by establishing reuse targets and goals at the beginning of a project minimise the impact on the timeline, budget, and scope and address challenges with logistics and infrastructure.

The alignment of these findings with the current priorities of the waste strategy goals in New Zealand (Ministry for the Environment- MfE, 2023b) adds weight to the findings. Addressing the deficiencies in recycling and waste infrastructure is not only a recognised issue within the industry but is also in line with the government's strategic direction, emphasising the urgency and importance of creating a more sustainable RCWR system. Wang et al. (2023) highlighted the need for focused efforts in areas with high CW generation and the importance of regional cooperation to manage CW effectively and achieve mutual benefits through collaborative governance.

4.5.2.3 Waste sorting

53% of participants emphasised the importance of active waste sorting as a standard practice in construction sites to enable accurate measurement by type and ensure optimal recycling outcomes. Several participants highlighted the influence of limited onsite space, lack of incentives to sort waste, and site footprint. Space limitations make accommodating separate bins for different materials challenging, particularly in smaller sites or highly dense developments. Construction density in certain areas, such as Auckland, adds complexity to waste sorting due to frequent bin pick-ups and truck movements. As **P11** stated, "*You often don't have the space you need to put enough skips to manage construction waste effectively*". Suggested strategies stressed the need for creative solutions, such as using smaller bins, tote bags, recognised signage, education, and well-fenced bins to overcome space limitations and contamination issues. Prior research on the influence of onsite space, incentives for recycling and the availability of resources to improve waste sorting (Hao et al., 2019; Wang et al., 2010).

This factor received moderate recognition, with approximately half of the participants acknowledging its importance. Participants with more than 15 years of overall and RCWR-related experience tended to recognise waste sorting more than those with less experience. Also, participants from executive-level management and advisory/consultancy services recognised the importance of waste sorting more than those in other management levels and sectors, see Table 4.2.

4.5.2.4 Material sourcing and procurement

53% of participants highlighted the importance of procuring materials aligned with the building design and considering available standard sizes in the market. **P10** stated, "*How do we reduce what we're buying? You need to try and order the right size*". Some participants highlighted challenges related to limited material choices, lack of substitution options, and the importance of local material availability. Considerations such as ethical supply chains, RCWR as a contract procurement term, health implications of certain materials, materials with high waste profiles, and the need for environmentally friendly alternatives were also mentioned. The viewpoints highlighted the influence of excess ordering due to supply chain issues; **P7** put it as "*not wanting to risk having supply problems, so they would rather overorder than deal with that underorder*". A proposed strategy is to emphasise the reuse of locally available materials to decrease dependence on overseas imports, which may be impacted by shipping challenges and increasing costs. The challenges of introducing new materials to the market stress the need for government incentives to encourage local production rather than relying solely on regulations.

Referring to Table 4.2, this factor did not show significant variations based on participant characteristics. Our results parallel the trends observed in the literature on CW reduction during the materials procurement stage. Efficient procurement and connecting design and construction phases are crucial for reducing CW and lowering construction costs in Egypt (Daoud, Omar, et al., 2023). Meanwhile, in the UK, material procurement accounts for 50% of project costs, highlighting its significant impact (Ajayi, Oyedele, Akinade, Bilal, Alaka, & Owolabi, 2017).

4.5.2.5 Data capture and waste performance

33% of the participants agreed that a data-driven approach helps drive behaviour change and sets targets for RCWR. Data capture establishes a baseline measurement of current waste performance and tracks the impact of changes to onsite practices. As **P4** stated, "*Data is king that helps make informed decisions and track where we currently are*". The participants raised concerns about the lack of comprehensive and accurate data, which can lead to assumptions and discrepancies in waste quantity figures. Improving data quality can help understand waste's economic value and drive behaviour change. The viewpoints emphasise the need for systematic data capture and reporting on RCWR practices, which involves working with waste operators to report waste diversion rates and implementing data capture platforms or databases to measure CW generation on sites. **P1** and **P5** emphasised the need for key performance indicators (KPIs) related to RCWR on the project level that are tied with rewards to hold site teams accountable and improve waste performance. However, having the correct data and educating site teams are required before the KPIs.

Interestingly, participants in residential construction recognised this factor more than others, suggesting that this factor may be of more significant concern for the residential construction sector, see Table 4.2. Our findings align with existing research in the field. For instance, in Hong Kong, the waste generation rate serves as a crucial performance indicator for benchmarking CW management practices, facilitating continuous improvement efforts (Lu, Chen, et al., 2015). Conversely, Kofoworola and Gheewala (2009) noted that the absence of comprehensive construction data limits waste reduction efforts in Thailand.

Table 4.2: Operational factors' summary

Factor's type	Size of Company		Overall experience		RCWR related experience		Highest degree				Level of management			Company services		
	SME	Large	≤15	>15	≤10	>10	Bachelors	Masters	Doctorate	other	Senior/ middle	Executive	Team Leader	Government	Residential construction	Advisory and consultancy services
Design optimisation	6/15	9/15	6/15	9/15	10/15	5/15	5/15	5/15	3/15	2/15	8/15	3/15	4/15	3/15	4/15	8/15
Logistics and infrastructure	6/15	9/15	6/15	9/15	10/15	5/15	5/15	5/15	3/15	2/15	8/15	3/15	4/15	3/15	4/15	8/15
Waste sorting	2/8	6/8	4/8	4/8	5/8	3/8	2/8	3/8	2/8	1/8	4/8	2/8	2/8	2/8	3/8	3/8
Material sourcing and procurement	4/8	4/8	3/8	5/8	4/8	4/8	2/8	3/8	1/8	2/8	4/8	2/8	2/8	2/8	3/8	3/8
Data capture and waste performance	4/6	2/6	4/6	2/6	4/6	2/6	3/6	2/6	0/6	1/6	3/6	1/6	2/6	0/6	5/6	1/6

4.5.3 Governance factors

4.5.3.1 Accountability and responsibility

40% of the participants emphasised the importance of accountability and collective responsibility for RCWR. As **P15** described, "*It is a collective responsibility, and to make a difference, we all have to do our part*". The construction industry is highly fragmented and challenges prioritising RCWR throughout the project. Disruptions in the global supply chain, cost increases, and pressure from clients to complete projects on time, with potential financial penalties for delays, add complexity to RCWR's responsibility.

The level of government responsibility was emphasised due to the local councils' ownership of most landfills and their vested interest in reducing waste sent to landfills. However, **P3** explained that "*the priorities for local government will vary from place to place. In Auckland, we have a more acute problem because there is an enormous amount of development happening here in residential*". In contrast, other regions faced fewer pressing issues, resulting in varying levels of urgency in RCWR efforts. Other viewpoints stressed the need for mandatory project waste plans and a level of enforcement and monitoring to hold accountability. However, concerns have been raised about how compliance will be monitored and enforced to ensure fairness. The importance of delegating responsibility for RCWR to the supply chain, which may include setting clear expectations in contracts, was also highlighted.

The results (see Table 4.3) indicate that accountability and responsibility are recognised to a moderate extent in RCWR. This factor is influenced by the management level, with higher-level management showing greater recognition. Consistent with the literature, accountability and responsibility and its impact on CW reduction received recognition in Australia (Shooshtarian et al., 2019; Udawatta et al., 2015).

4.5.3.2 Regulation and Policy

87% of the participants recognised the influence of regulation and policy on RCWR. Some participants stressed that education and awareness should precede regulation, suggesting that simple changes can be made without burdening contractors and developers. The need to conduct a cost-benefit analysis before implementing regulations was also highlighted. A raised point by **P11** indicated that regulations are necessary but can get diluted during implementation, and opposition to regulations often arises from concerns about cost and time constraints.

Regarding the building code, there are restrictions regarding the use of reused or recycled materials and the regulation of new products. The challenge lies in getting the building code to support more sustainable building materials without increasing costs. **P14** stated, "*The building code is a floor, not a ceiling. So, it is a minimum requirement, not the pass requirement*". Thus, compliance does not necessarily mean environmentally friendly. Regional differences in building codes exist, but material choices are influenced by availability, cost, performance, and building code compliance.

The regulation and policy factor received the highest recognition in the governance category (refer to Table 4.3). Participants among SMEs and large companies, academic qualifications and experience exhibited relatively similar recognition levels. Executive or senior/middle management participants had the highest recognition of regulation and policy, suggesting that higher-level management, especially executives, acknowledge the significance of regulation and policy in RCWR. Advisory and consultancy services strongly recognise the importance of regulations and policies. At the same time, government participation and residential construction had lower but still notable recognition. The findings resonate with past studies on the importance of regulatory changes, incentives, and penalties in promoting CW reduction (Daoud, Othman, et al., 2023; Liu, Yi, & Wang, 2020).

4.5.3.3 Material Standardisation

Material standardisation significantly contributes to CW, particularly off-cuts. As **P6** explained, "*If the standard size materials you have and the building design don't line out, then you're always going to get a problem with they're going to be a mismatch, and it's going to end up being waste*". The participants highlighted that limited options in construction materials are due to the difficulty of ensuring compliance with building code standards. Moreover, concerns about the durability of recycled materials and the need to select materials with a proven track record of performance over a long period were also highlighted. Industry associations can play a crucial role in promoting standardised materials in parallel with education and a thorough understanding of standard material sizes to design with RCWR in mind.

38% (see Table 4.3) recognise the influence of material standardisation in RCWR. This percentage varies across participant characteristics, such as the management level and company services. Participants in senior/middle management roles from advisory/consultancy services notably acknowledge material standardisation in RCWR. The findings resonate with enhancing the coordination between design dimensions and standard material specifications to improve the building's constructability and prevent unnecessary off-cuts (Ajayi, Oyedele, Akinade, Bilal, Alaka, et al., 2017). Furthermore, considering standard material sizes in design reinforces the importance of efficient RCWR practices (Tu et al., 2023).

4.5.3.4 Collaboration and Partnership

Collaboration and communication among partners in the residential construction and waste sectors, including industry groups, peer-to-peer learners, researchers, and government initiatives, underscore 38% of viewpoints. Sharing knowledge and best practices and working together on collaborative projects are crucial for driving change; as **P3** said, "*Getting collaborative projects between the industry and researchers does drive change*". A call is raised for working with government initiatives to support organisations in becoming product stewardship accredited. Several participants highlighted breaking down silos and promoting collaboration within the industry as essential to set standards, facilitate data-driven decision-making, and establish industry-wide benchmarks for sustainable RCWR. Viewpoints emphasised the need for a holistic approach involving various elements such as government support, workforce training, incentivisation, research, and education. According to **P13**, "*The main part will be getting the industry to work together, particularly across the supply chain*".

Across all participants' characteristics (see Table 4.3), those with extensive experience in overall and RCWR-related fields, higher-level management positions, and those from the government and advisory/consultancy services sectors strongly emphasise this factor. However, the residential construction industry's emphasis on collaboration and partnership must be improved. Aligning with research in Europe, Gálvez-Martos et al. (2018) outlined the importance of communication and involvement in waste management systems. The research highlights i) participatory and inclusive planning where interested parties meet regularly to assess system performance, establish or update objectives, and monitor progress against benchmarks and ii) promoting inclusivity at all levels, including setting local waste platforms with decision-making authority as a recommended practice.

Table 4.3: Governance factors' summary

Factor's type	Size of Company		Overall experience		RCWR related experience		Highest degree				Level of management			Company services		
	SME	Large	≤15	>15	≤10	>10	Bachelors	Masters	Doctorate	Other	senior/ middle	Executive	Team Leader	Government	Residential construction	Advisory and consultancy services
Accountability and responsibility	3/6	3/6	3/6	3/6	4/6	2/6	2/6	3/6	0/6	1/6	3/6	1/6	2/6	2/6	2/6	2/6
Regulation and policy	5/13	8/13	5/13	8/13	9/13	4/13	4/13	5/13	2/13	2/13	6/13	3/13	4/13	3/13	3/13	7/13
Material standardisation	3/5	2/5	3/5	2/5	3/5	2/5	2/5	1/5	2/5	0/5	4/5	0/5	1/5	0/5	2/5	3/5
Collaboration and partnership	3/8	5/8	2/8	6/8	5/8	3/8	2/8	3/8	2/8	1/8	4/8	1/8	3/8	3/8	1/8	4/8

4.5.4 Economic factors

4.5.4.1 Cost of waste

A higher waste levy influences exploring alternative waste disposal methods and improves RCWR practices. According to **P7**, "*We've already raised the waste levy, but it needs to be at a much higher level*". Another viewpoint (**P1**) elaborated that implementing CW reduction may incur additional costs due to the resources needed for waste sorting, which increases construction costs. However, a waste levy that is lower than the cost of implementing RCWR practices might outweigh the benefits of RCWR and encourage landfilling.

Implementing taxes or levies on polluters has been widely recognised in Europe (Gálvez-Martos et al., 2018), Australia (Newaz et al., 2022), and China (Wang, Wu, et al., 2019) to encourage responsible CW management and reduce environmental impact. This strategy directly links the cost of waste treatment to the quantity of waste generated, often by imposing charges based on the units produced. 40% of participants addressed the cost of waste, which is consistent based on the company's size, overall experience, and management level. Participants with more experience and higher management levels are more aware of the financial implications of RCWR, which is especially relevant for participants in leadership roles. See Table 4.4.

4.5.4.2 Market development

Market development should encourage more waste management service providers, increasing competition to promote innovation in the recycling and waste management sector, as highlighted by 28%. For instance, **P11** said, "*Competition is great; that is why Auckland has more operators than other areas, and that is why you have projects, and that is why people working onsite understand what they need to do*". More competition would encourage businesses to explore alternative recycling options. Additionally, further research is required to address concerns about the safety and effectiveness of recycled materials, increase confidence in their usage, and expand the market. As **P14** stated, "*Building residential construction at speed, volume, and affordable cost, but also sustainability tends to increase the cost and reduce the affordability because we haven't got the scale in New Zealand to produce millions of tonnes of a particular product because our market is still small*".

In alignment with our findings, Ratnasabapathy, Alashwal and Perera (2021) indicated that the lack of an established market for reusable/recycled construction materials and government incentives influence effective CW reduction. Moreover, in the US, Ibrahim (2016) highlighted that regulating and incentivising recycling practices is crucial to developing markets for diverted materials and driving competition.

The results suggest that in large companies, all participants recognised market development as a relevant factor in RCWR (Table 4.4). However, it still needs to be recognised in SMEs, which indicates a stark difference in perception between large and SMEs regarding the importance of market development in RCWR. Additionally, the type of company services influences how participants perceive this factor, with advisory and consultancy services showing a higher recognition than residential construction and government sectors.

4.5.4.3 Financial incentives

Money is seen as a significant motivator in driving RCWR efforts, while cost is a hindrance. Participants highlight the importance of financial incentives, such as green funding, sustainability bonds, and contracts that reward achieving specific waste performance metrics. Financial incentives encourage companies to improve and prioritise RCWR practices. **P14** explained, "*We need to look at residential structure with a system view as to what parts of that supply chain and that system are contributing to the problem of not being sustainable enough, where people are aware, and businesses seek a commercial value innovation to do things differently*". Further, **P10** reflected, "*The recycling culture needs to change, and manufacturers should be incentivised to create product recycling points*".

Consistent with studies in Hong Kong (Bao, Lee, & Lu, 2020) and the US (Ibrahim, 2016); finding the right balance between costs and financial returns is a critical criterion for decision-making when adopting sustainable practices. Although incentives were provided by both governments, sustaining the economic viability of recycling plants was not sustainable. Stakeholders were found to opt for a financial-based incentive waste reduction plan rather than penalties (Mahpour & Mortaheb, 2018).

Based on the findings in Table 4.4, the economic category of RCWR highlights financial incentives as the most recognised factor with 47%. Both SMEs and large companies acknowledge the significance of financial incentives in RCWR. Participants at the executive level showed the highest recognition, followed by senior/middle management, suggesting that higher-level management is more likely to acknowledge the importance of financial incentives. Advisory and consultancy services value financial incentives the most. However, residential construction has moderate recognition, which implies differences in perception among various organisations about the role of financial incentives in RCWR.

Table 4.4: Economic factors' summary

Factor's type	Size of Company		Overall experience		RCWR related experience		Highest degree				Level of management			Company services		
	SME	Large	≤15	>15	≤10	>10	Bachelors	Masters	Doctorate	Other	Senior/ Middle	Executive	Team Leader	Government	Residential construction	Advisory and consultancy services
Cost of waste	3/6	3/6	2/6	4/6	3/6	3/6	2/6	3/6	0/6	1/6	3/6	1/6	2/6	1/6	3/6	2/6
Market development	0/4	4/4	1/4	3/4	4/4	0/4	1/4	2/4	1/4	0/4	1/4	1/4	2/4	1/4	0/4	3/4
Financial incentives	3/7	4/7	3/7	4/7	5/7	2/7	3/7	2/7	1/7	1/7	2/7	3/7	2/7	0/7	3/7	4/7

4.5.5 Innovative and technical factors

4.5.5.1 Level of innovation and technology

Adopting the right technology is essential for RCWR, receiving 47%. Technologies like BIM are valuable for efficient planning and future-proofing construction projects. BIM can enable the development of material passport systems and make it easier for designers to include that information in their BIM models. Additionally, modularity and advancements like 3D concrete printing enable RCWR. However, **P14** stressed that "*If you want to adopt this technology, what would be the sustainable way or most relevant material to use?*". In other words, choosing materials and addressing associated challenges are critical factors in adopting these technologies effectively towards more sustainable construction and RCWR approaches. Considerations for introducing new innovative construction methods aimed at RCWR include safety and longevity. The viewpoints emphasise the need to consider the long-term waste flow and potential for recycling or reuse throughout the entire life cycle of the construction project. Thus, taking a holistic approach, considering the overall impact and sustainability of the new methods, was suggested to address any challenges.

Constraints related to the Council's ability to embrace new and innovative construction products and processes were highlighted by **P7**. These constraints include i) risk aversion due to past issues with projects not meeting building code requirements, leading them to prefer established products with a track record. ii) Bureaucratic Bottleneck approval process, iii) shared and multiple liability as New Zealand's construction law involves joint and several liability, where all parties involved in a project share responsibility. Iv) Cost Pass-On as suppliers may increase prices to account for potential future liability, further impacting construction costs.

Suggested strategies highlighted the need for labelling and accreditation systems that recognise basic training and RCWR practices, allowing companies to demonstrate commitment to RCWR. **P8** said, "*Labelling in terms of your recycled products and product choice also accreditation in terms of if we're still working in a voluntary system where the only way getting recognition for doing this best practice is by doing it voluntarily then there is accreditation*". The statement implies that the visibility provided by accreditation and labelling is a powerful tool to encourage and promote sustainable practices in the construction industry.

The influence of innovation and technology on CW reduction, as discussed by Pozo, Akabane and Tachizava (2019) and Liu et al. (2015), is multifaceted. Technical progress in construction methods and products benefits companies and the system, emphasising efficiency and scale. Micro and small businesses view innovation as enhancing development and productivity. Participants from large companies show a higher level of agreement regarding the influence of innovation and technology on RCWR than SMEs, see Table 4.5. Given the magnitude of the build projects in large companies, they may better understand this factor's influence on RCWR. More experienced participants showed the highest level of agreement, but the highest degree attained by participants did not impact their agreement. This factor consistently received recognition among senior and middle management participants in all services, indicating potential improvement in RCWR with higher levels of innovation and technology.

4.5.5.2 Modularity in residential construction

33% of viewpoints highlighted Offsite manufacturing (OSM) and prefabrication as some aspects of implementing modularity to positively influence RCWR, where units are built offsite in a more controlled environment, resulting in less waste and increased safety. Highlighted constraints that currently limit OSM's widespread adoption are customisation requirements, training needs, size of the project, and cost considerations. Further testing, side-by-side comparisons, and training efforts are crucial for realising OSM's full potential in RCWR. **P9** suggested, "*We need to have a side-by-side model whereby two houses are built, one is a standard build, the other is a prefab build, and we look at the benefits*".

Evidence has shown that prefabrication can significantly reduce up to 90% in CW (Cheng et al., 2022). Researchers are increasingly exploring the connection between prefabrication, modular construction, and product lifecycle management in the circular economy and waste reduction context. Modularity can potentially increase materials' recovery, recycling, and circularity, making it a crucial factor in RCWR (Laovisutthichai, Lu, & Bao, 2022; Machado & Morioka, 2021).

Participants from large and SME companies show a similar level of agreement regarding the influence of modularity on RCWR in residential construction (see Table 4.5). Among those, participants with over 15 years of overall industry experience and mostly less or equal to 10 years of experience in RCWR. The level of agreement is observed to be higher among those with higher education degrees, specifically master’s and doctorate degrees, while participants at different management levels show varying degrees of agreement. Those who provide advisory or consultancy services strongly agree that modularity influences RCWR, indicating their expertise in the overall aspects of the residential sector.

4.5.5.3 Research and development (R&D)

R&D in developing a market value for RCWR should focus on modular and reusable products and innovative building materials. The challenge lies in creating sustainable products, avoiding multi-material compositions that hinder deconstruction, and meeting durability and safety standards for recycled materials. Concerns were raised regarding the R&D cost, emphasising a need for collective investment rather than relying solely on private companies to drive progress in sustainable construction materials. According to **P14**, "*It is our duty to create a pathway to market that current waste as well; it's a matter of priority and funding*".

A robust economy allows the government to allocate more financial resources to environmental protection efforts, such as advancing cleaner technology through incentivising R&D (Hove & Tursoy, 2019). Furthermore, Bao et al. (2023) revealed that collaboration among research institutions and construction companies in China has led to unique recycled products, providing a competitive advantage in shaping market prices and boosting profitability. Participants with higher overall experience, RCWR-related experience, and those in senior/middle management positions are more likely to recognise the significance of R&D in RCWR. This indicates that varying levels of awareness and priority may be placed on R&D depending on participants' backgrounds and organisational roles (see Table 4.5).

Table 4.5: Innovative and technical factors' summary

Factor's type	Size of Company		Overall experience		RCWR related experience		Highest degree				Level of management			Company services		
	SME	Large	≤15	>15	≤10	>10	Bachelors	Masters	Doctorate	Other	Senior/ Middle	Executiv e	Team Leader	Government	Residential construction	Advisory and consultancy services
Level of innovation and technology	2/7	5/7	3/7	4/7	5/7	2/7	3/7	3/7	0/7	1/7	5/7	0/7	2/7	2/7	2/7	3/7
Modularity in residential construction	2/5	3/5	2/5	3/5	4/5	1/5	1/5	2/5	2/5	0/5	2/5	1/5	2/5	0/5	0/5	5/5
Research and development	0/3	3/3	1/3	2/3	2/3	1/3	2/3	0/3	0/3	1/3	3/3	0/3	0/3	1/3	1/3	1/3

4.5.6 Social and behavioural factors

4.5.6.1 Awareness and education

All participants emphasised the influence of creating awareness about the available resources and best practices for RCWR and educating all stakeholders on how to perform RCWR practices. **P10** indicated, "*It's education. People will do it, and they are good at doing it once they know*". Suggested strategies highlighted the need for universities to focus on practical education by exposing students to real-life projects and construction sites. This exposure is critical in theoretical courses like engineering and architecture, where RCWR may not be explicitly covered. **P11** stated, "*Drive that education, which also drives onsite behaviour, is what the focus should be*". Sustainability and RCWR should be integrated into every role in the construction industry rather than being limited to specific positions.

Education changes the industry's perception of waste, which is seen as a problem rather than an opportunity. Individuals need to understand the impact of waste and be incentivised to reduce it. **P7** suggested that "*Exhibits, webinars, online videos, and directories of businesses*" can help streamline the process. Furthermore, creating awareness among the public about the environmental impact of construction materials to drive demand for sustainable materials should be encouraged, leading to more environmentally friendly options in the market. Improving awareness and education requires determination, strategic planning, and getting everyone on board with RCWR concepts, particularly designers.

Resonating with findings in Iran, Mahpour and Mortaheb (2018) highlighted raising employee awareness and recognising their contributions to waste reduction by offering training and education. Furthermore, Liu, Yi and Wang (2020) pointed out that training and education enhance stakeholders' professional ethics and improve individuals' commitment to CW reduction activities. Table 4.6 shows that participants from diverse backgrounds, including different company sizes, experience levels, management roles, and company services, overwhelmingly agree on the influence of awareness and education on RCWR. This consensus suggests that raising awareness and providing education in this context is widely recognised and encouraged.

4.5.6.2 Culture and willingness to change

73% of participants were critical of the industry's culture towards waste and willingness to change. **P1** noted, "*The biggest constraint is the culture; people taking an effort to actively minimise waste onsite*". **P7** expressed that "*Resistance to change is particularly entrenched in this industry*". One participant, **P10**, indicated that younger workers are generally more receptive to learning about RCWR, saying: "*People who have been in the industry for a long time can't be bothered. It's all too hard, or they don't* *understand*". The resistance to change is attributed to a lack of awareness among stakeholders about their role and the importance of waste reduction. Additionally, there is a perception that managing multiple waste streams onsite requires more effort than using a general skip bin. The lack of understanding about the potential contributions of waste reduction, the efficiency of the bin culture, and the perspectives of clients and builders in relation to waste reduction are also contributing factors.

The influence of culture on CW reduction is evident in literature, as indicated by Crawford, Mathur and Gerritsen (2017) and Ding et al. (2018). The prevailing culture within the construction industry can hinder waste reduction. However, there is a potential cultural shift among newer generations, who are more likely to integrate waste reduction into the design process. A higher level of agreement on this factor is observed among participants from large companies, those with more overall experience, and those with more experience related to RCWR (Table 4.6). This indicates that cultivating a culture of change and willingness to adapt is essential for effective RCWR, especially in larger companies and among experienced professionals.

4.5.6.3 Peer pressure

Peer pressure can drive positive change in the industry by promoting higher standards and showcasing successful examples. **P13** proposed, "*A bit of peer pressure. If other builders start to do this as a point of difference or a selling point, it will help shift people to that next level. If we started to look at attributes beyond price, I think people will become more discerning around this*". The need for training would equip site supervisors with the knowledge and skills to positively lead onsite RCWR and control the negative impact of workers' attitudes, which can hinder RCWR progress.

Similar findings in the UK (Ogunbiyi, Goulding, & Oladapo, 2014), peer pressure and a growing recognition of the significance of a positive construction image can influence individuals' behavioural intentions differently regarding CW reduction. Moreover, peer pressure can foster a culture of sustainability within the industry and create a sense of social responsibility and motivation for CW reduction. 13% of participants highlighted the influence of peer pressure on RCWR, regardless of their characteristics. According to Table 4.6, this factor is not considered a significant driver of RCWR efforts.

Table 4.6: Social and behaviour factors' summary

Factor's type	Size of Company		Overall experience		RCWR related experience		Highest degree				Level of management			Company services		
	SME	Large	≤15	>15	≤10	>10	Bachelors	Masters	Doctorate	Other	Senior/ Middle	Executive	Team leader	Government	Residential construction	Advisory and consultancy services
Awareness and education	6/15	9/15	6/15	9/15	10/15	5/15	5/15	5/15	3/15	2/15	8/15	3/15	4/15	3/15	4/15	8/15
Culture and willingness to change	4/11	7/11	5/11	6/11	8/11	3/11	3/11	4/11	2/11	2/11	6/11	1/11	3/11	3/11	4/11	4/11
Peer pressure	0/2	2/2	1/2	1/2	2/2	0/2	1/2	1/2	0/2	0/2	1/2	0/2	1/2	1/2	1/2	0/2

4.5.7 Organisational factors

4.5.7.1 Influence of leadership and commitment

47% of participants viewed leadership and commitment to sustainable practices as influencing project requirements and driving RCWR prioritisation. The client push for RCWR and industry-wide movement are seen as a powerful force driving change across the sector. Alternatively, a Top-down approach and a clear management mandate for RCWR are essential for driving action in RCWR. Viewpoints highlight the need for management to prioritise RCWR and provide the necessary resources and guidance to implement effective practices. For example, **P3** said: "*A very high level of support from the management to work on waste, so having the mandate from management to do something about it*". **P4** recognised a "*coalition of willing*" within the industry, comprising individuals and organisations actively seeking to make positive changes in waste management and environmental performance. These entities drive innovation and inspire others to adopt sustainable RCWR practices.

The influence of management leadership in CW reduction, as highlighted in Malaysia and the UK (Liu et al., 2015; Ng, Tan, & Seow, 2017; Shan et al., 2018), underscores the importance of a top-down approach and good governance facilitates efficient coordination and communication for CW reduction. As Table 4.7 shows, large companies are more likely to acknowledge the significance of leadership and commitment in RCWR. Participants with less than or equal to 15 years of overall experience recognised this factor more substantially, indicating that those with more extensive experience value leadership and commitment in RCWR more. Results are consistent among those with ten or fewer years of RCWR-related experience. Interestingly, all participants with high degrees recognised this factor, indicating that higher-level education promotes leadership and commitment in RCWR. Senior/middle management participants showed a relatively higher acknowledgment of this factor. Recognition levels vary among company services, with government participants having the lowest recognition.

4.5.7.2 Expertise and training gap

40% of the participants acknowledged the influence of expertise and training gaps on RCWR. For instance, smaller residential construction companies are eager to improve their RCWR practices but often lack in-house expertise and struggle with navigating the technical aspects of RCWR compared to larger firms. In contrast, larger firms may have dedicated sustainability personnel or teams. Participants emphasised the need for clear guidelines, assistance, and support for smaller companies to understand reporting requirements and measurement methodologies to bridge the knowledge gap and implement sustainable RCWR practices effectively. One of the challenges is the limited availability of training programs specific to RCWR, and efforts often rely on "*in-house*" initiatives (**P5**). Other challenges are workforce turnover and language diversity. As **P9** said, "*The turnover can be quite high, new people coming in, and they need to be trained to do this differently. Also, a workforce that will not necessarily speak English, so you need to be able to translate this into different languages*". The findings are consistent with a recent study by Omer, Rahman and Almutairi (2022), which revealed that small to medium enterprises and large enterprises face different challenges based on their organisational characteristics. Additionally, a multicultural workforce and language diversity hinder CW reduction efforts (Shazwan et al., 2017).

Larger companies and participants with more extensive experience tend to recognise this factor more readily than SMEs and those with less than 15 years of overall experience. However, participants with less or equal to 10 years of experience related to RCWR demonstrate better recognition than those with higher experience, indicating that this factor is highly observed regardless of experience level. The recognition of this factor is not strongly correlated with the degree attained but is somewhat higher among senior/middle management compared to those in other roles. The type of company service does not strongly influence recognition since it is relatively consistent across different services, see Table 4.7.

Table 4.7: Organisational factors' summary

Factor's type	Size of Company		Overall experience		RCWR related experience		Highest degree				Level of management			Company services		
	SME	Large	≤15	>15	≤10	>10	Bachelors	Masters	Doctorate	Other	Senior/ Middle	Executive	Team leader	Government	Residential construction	Advisory and consultancy services
Influence of leadership and commitment	2/7	5/7	5/7	2/7	7/7	0/7	2/7	4/7	1/7	0/7	4/7	1/7	2/7	1/7	3/7	3/7
Expertise and training gap	1/6	5/6	2/6	4/6	4/6	2/6	2/6	2/6	1/6	1/6	4/6	1/6	1/6	2/6	1/6	3/6

4.5.8 Process and procedure factors

4.5.8.1 Modelling best practices

27% of the viewpoints revolved around the positive influence of promoting and encouraging good waste practices. A suggested strategy is creating a business case, particularly in profit-driven industries, to highlight the financial benefits of RCWR, such as cost savings, which can effectively promote best waste practices. **P8** encouraged industry leaders and associations to "*demonstrate what good looks like and provide support for making it as easy to implement as possible*". The viewpoints highlighted the potential positive influence of voluntary actions, even without regulatory requirements, which will encourage voluntary adoption of these practices across all scales and sectors, especially for smaller-scale builders. Simplifying the message is crucial to ensure that RCWR practices are easily understood and followed. Also, making RCWR practices accessible and uncomplicated increases the likelihood of adoption. As **P1** said, "*People are likely to adapt. If it is too technical or too compulsive, then it might not get the message we are trying to pass on*".

The findings are consistent with prior research in the field. For example, access to information on best practices and economic benefits was valuable for understanding the business case for waste reduction in the UK (Oyenuga & Bhamidimarri, 2015). This factor received relatively lower recognition among SMEs than among large companies, suggesting that larger companies are more likely to prioritise and model best practices in RCWR (see Table 4.8). Participants with over 15 years of overall experience and those with less than 10 years of RCWR-related experience mentioned this factor more, indicating a general awareness of the importance of modelling best practices in RCWR. Senior and middle management participants were more inclined to consider modelling best practices. Government organisations and advisory/consultancy services participants were aligned in recognising the significance of this factor.

4.5.8.2 Unlocking circularity

33% of viewpoints on implementing circularity and RCWR acknowledge that while promising initiatives exist, the circular economy has yet to be widely implemented in New Zealand. The participants attribute the poor progress in circular waste models to the lack of infrastructure, willingness, drive, and stakeholder interest. Additionally, business models fixed on a linear model (take, make, use, dispose) find it hard to progress in RCWR. Proposed strategies to unlock circularity in the field of RCWR involve adopting innovative construction methods, developing new products, and changing companies' perspectives and approaches to facilitate the transition towards circular business models. Other suggested strategies focused on the positive influence of material take-back schemes and product procurement in promoting circularity. **P4** expressed, "*If a material can be recovered to be reused in new material: A. it is diverted from landfill and B. it is a bit of a circular economy kind of an outcome*". A concern was raised about assessing the overall resource consumption involved in transporting and deconstructing materials and evaluating the long-term impacts and environmental consequences of reusing specific materials, such as plastics.

Some viewpoints were particularly critical of the need to focus on upstream activities and the importance of designing buildings and products with circularity from the start, as well as considering the entire life cycle for potential reuse in the residential sector to unlock circularity in RCWR. Challenges in circularity for residential construction include addressing the long lifespan of materials, predicting future needs and trends, and preserving material value. According to P6, "*Time horizon is difficult to manage when talking about circular solutions, because how can we consider a business model that involves a company we set up now, that is still going to be here in the year 2120? It involves a degree of planning that is slightly unrealistic*".

Aligning with a study in Ireland, Kelly, Burke and Gottsche (2019) revealed that the circular economy concept aims to create restorative and regenerative systems. Opportunities are shifting from the end-of-life approach, focusing on restoration, renewable energy use, eliminating toxic materials, and designing waste out. Furthermore, Hossain et al. (2020) highlighted the constraints to implementing circularity as the choice of materials, available supply of materials, profitability, and future changes in design. Participants from large companies agreed on unlocking circularity higher than those from SMEs, indicating a potential focus on circular economy practices in larger organisations, see Table 4.8. Participants with more than 15 years of experience and senior/middle management roles strongly preferred this factor. It appears that participants in planning and decision-making roles are concerned about circularity. The advisory/consultancy services had more substantial views on this factor, with government and residential construction sector participants suggesting potential priority divergences.

4.5.8.3 Business model shift

27% of participants viewed that a shift in the business model involves implementing standardised practices and guidelines to ensure consistency and maximise resource recovery. Establishing standardised processes and guiding everyone involved in the construction process can simplify RCWR efforts and improve compliance. **P2** suggested providing "*Advice on processes and standard analysis of how to work in the most efficient way*". The focus on enhancing upfront processes primarily pertains to construction projects' design and planning phase. However, **P14** stressed that "*We need to look at residential structure with a system view as to what parts of that supply chain and system contribute to the problem of not being sustainable enough*".

Aligning with the findings of case studies conducted in Germany, the Netherlands, Poland, and Denmark, standardising processes and construction methods can lead to the successful development of circular solutions in the construction industry (Kozminska, 2019). This factor received a lower rating among SMEs than large companies. According to Table 4.8, those with more than 15 years of overall experience and participants with the highest degrees (master's and doctorate) showed a relatively higher interest in business model shifts. Senior and middle management participants from diverse services in large companies shared recognition of this factor. This suggests that the participants are aligned in their awareness and understanding of how the business models in RCWR are evolving.

Table 4.8: Process and procedure factors' summary

Factor's type	Size of Company		Overall experience		RCWR related experience		Highest degree				Level of management			Company services		
	SME	Large	≤15	>15	≤10	>10	Bachelors	Masters	Doctorate	Other	Senior /Middle	Executive	Team leader	Government	Residential construction	Advisory and consultancy services
Modelling best practices	1/4	3/4	3/4	1/4	3/4	1/4	2/4	1/4	0/4	1/4	3/4	0/4	1/4	1/4	3/4	0/4
Unlocking circularity	2/5	3/5	1/5	4/5	3/5	2/5	3/5	1/5	1/5	0/5	4/5	0/5	1/5	1/5	1/5	3/5
Business model shift	1/4	3/4	2/4	2/4	4/4	0/4	1/4	2/4	1/4	0/4	4/4	0/4	0/4	1/4	1/4	2/4

4.5.9 Environmental factors

4.5.9.1 Environmental impact of residential construction

33% of the participants highlighted that realising the environmental impact of residential construction activities drives RCWR. Participants stressed the importance of considering the carbon footprint and reducing the environmental impact of materials being produced in the first place. Rethinking material and product design and efficient construction methods are crucial in reducing the environmental impact, suggesting that working with the suppliers can significantly reduce waste. **P14** stated, "*The choice of material would be readily reusable or compostable, which has a lesser environmental impact. So, even when we have certain wastages, it might not be very alarming in terms of environmental aspects*". **P5** elaborated on the industry point of view that suppliers and manufacturers should be accountable for the end-of-life management of their products rather than placing the entire responsibility on consumers. This approach helps alleviate the burden on consumers regarding the disposal or recycling of products after use.

Consistent with prior research findings, reducing environmental impacts across a house's life cycle primarily depends on making environmentally aware choices, from the material manufacturing process to sustainable design choices and the material's end-of-life environmental impact (Crawford, Mathur, & Gerritsen, 2017; Cuéllar-Franca & Azapagic, 2012). Participants from diverse backgrounds, including large companies and SMEs, have shown a consistent understanding of the environmental impact of residential construction, as depicted in Table 4.9. Notably, those with more experience and higher degrees have expressed a more profound concern. However, even those with less experience have demonstrated a strong awareness, indicating that environmental consciousness is a driving force in developing the field in New Zealand. This also presents significant opportunities for collaboration between government organisations, advisory and consultancy services, and residential construction participants.

4.5.9.2 Environmental aesthetics and finite resources

This factor is related to the raised concerns about the consequences of landfills, as waste is not viewed as a significant issue. **P5** stressed, "*It is really important to make quite a big deal about the instances where landfills become huge sources of contamination, either through leaching into the groundwater or erosion*". The viewpoint highlighted the impact of building more landfills and the finite nature of valuable materials, encouraging the best practices for waste disposal. Specifically, connecting the impact of waste to climate change and highlighting that waste in landfills contributes to global warming with far-reaching impacts that people are starting to feel.

Disposing of CW in landfills has severe environmental impacts, such as land degradation, habitat destruction, soil and groundwater contamination, and emissions (Crawford, Mathur and Gerritsen (2017). Growing environmental concerns and awareness have succeeded in recognising the importance of diverting CW away from landfills to maximise the value of materials, reduce the need for new resources, and mitigate the environmental impacts associated with resource extraction, processing, and manufacturing. Since only one participant out of 15 brought up this factor, it may be a minor concern among the participants in this study; refer to Table 4.9.

Table 4.9: Environmental factors' summary

Factor's type	Size of Company		Overall experienc e		RCWR related experienc e		Highest degree				Level of management			Company services		
	SME	Large	≤15	>15	≤10	>10	Bachelors	Masters	Doctorate	Other	Senior/ Middle	Executive	Team leader	Government	Residential construction	Advisory and consultancy services
Environmental impact of residential construction	2/5	3/5	2/5	3/5	4/5	1/5	2/5	2/5	1/5	0/5	4/5	0/5	1/5	1/5	2/5	2/5
Environmental aesthetics and finite resources	0/1	1/1	1/1	0/1	1/1	0/1	1/1	0/1	0/1	0/1	1/1	0/1	0/1	0/1	1/1	0/1

4.6 Discussion and Practical Implications

A conceptual framework illustrating the resulting factors and related categories is developed and illustrated in Figure 4.3. The results revealed that successful implementation of RCWR is contingent upon (i) an understanding of the environmental impact of residential design and construction, (ii) market expansion for waste materials and circular materials, (iii) regulatory framework and policy interventions, and (iv) organisational strategy and willingness to change. On the governance level, local councils and central government exhibit inconsistent prioritisation of RCWR due to varied interests. Consequently, there is limited development and implementation of legislation aimed at RCWR and promoting sustainable practices (Llatas et al., 2021). Ambiguities and confusion regarding existing government legislation related to responsibility in CW management hinder stakeholders' engagement in sustainable construction practices and RCWR efforts (Quiñones et al., 2021).

In New Zealand, the local councils are primarily responsible for waste management, including CW (Ministry for the Environment- MfE, 2023b). The New Zealand Waste Strategy specifies goals for waste reduction, including CW; however, these goals are optional rather than compulsory. Furthermore, the building code focuses solely on the safe disposal of CW, failing to address material standardisation and environmental impact (Building Performance, 2024). This optional aspect and limitation in addressing RCWR hinder the ability to enforce accountability and achieve sufficient RCWR outcomes, ultimately impacting the promotion and implementation of RCWR practices. The absence of standardised units of measurement for CW data at the local level leads to inconsistencies that impede accurate assessment and monitoring of waste generation, diversion, and recycling rates (Hossain et al., 2020). Additionally, the limited availability of comprehensive national data on CW obstructs the formulation of evidence-based policies and regulations that support RCWR initiatives (Wu et al., 2022).

Design decisions for RCWR can be optimised by the client's interest and design requirements, management support, and material standardisation (Ajayi & Oyedele, 2018; Sezer, 2017). Material standardisation is a critical consideration for designing out waste, as off-cut waste resulting from customisation requirements can be avoided (Duan et al., 2019). In addition, incentivising the adoption of innovative construction methods like BIM enhances design and RCWR outcomes (Lindblad & Karrbom Gustavsson, 2021).

Figure 4.3: A framework of factors influencing RCWR in New Zealand.

Figure 4.4 outlines the priority areas essential for developing a strategy for RCWR in New Zealand. The first element is promoting education and awareness to drive behavioural change (Yazdani et al., 2021). Behaviour change from a consumption approach to an approach that emphasises sustainable use of resources and waste reduction requires time and effort (Bandh et al., 2024). Thus, New Zealand should implement a holistic educational approach. Results suggested that education must be integrated across all stages of the construction process and offered to all stakeholders involved in RCWR. Tailored education and training programs are encouraged at an industry level and incorporated into university curricula and apprenticeship programs. Education will create awareness about the choices and available options for RCWR and promote collaboration. Working collectively and breaking silos allows for considering different perspectives and experiences, which enhances decision-making and fosters shared responsibility (Zhu, Meng, & Zhang, 2021).

Implementing a comprehensive view of the RCWR system requires credible data and addressing the limitations of building code. Data-driven decision-making helps benchmark progress, measure performance, and plan infrastructure. Similar to findings in Australia, creating a policy framework aimed at reducing waste landfilling and taxing the polluter will help preserve the economic value of these resources (Shooshtarian, Maqsood, & Wong, 2024). Thus, establishing a system that rewards performance and incentivises successful RCWR is a powerful driver. Conversely, penalising waste generation increases the cost of waste, leading to increased motivation and commitment to achieving effective RCWR.

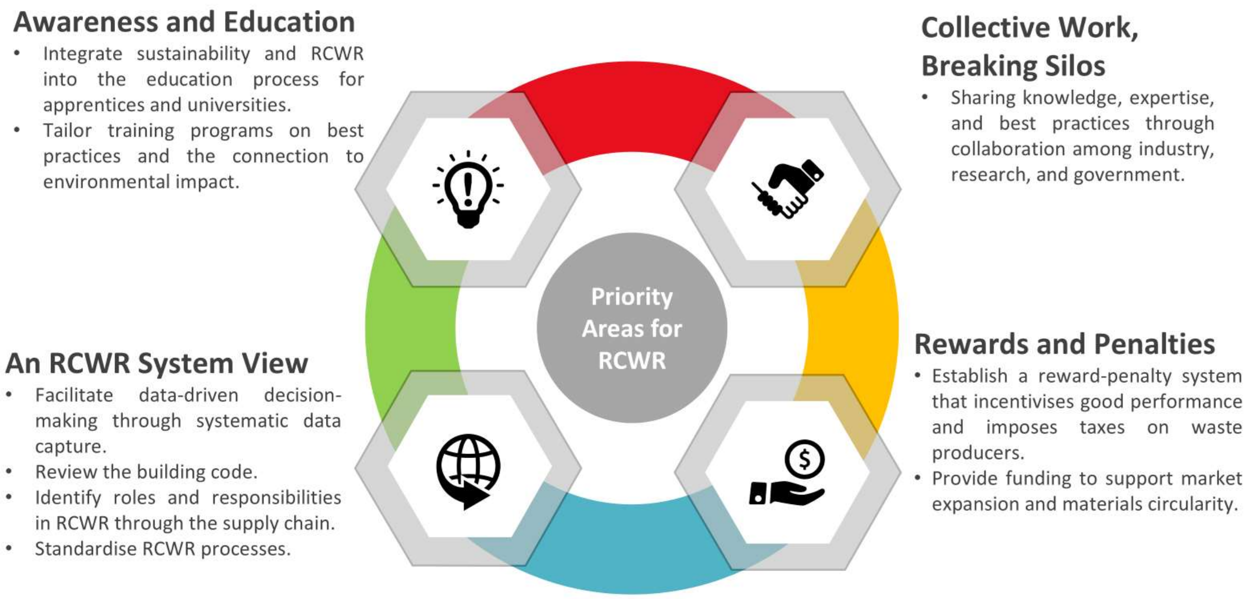

Figure 4.4: Priority Areas for RCWR in New Zealand

4.7 Conclusion

This qualitative research paper investigated the factors influencing RCWR in New Zealand based on a sample size of 15 participants. The findings revealed a comprehensive framework of 25 factors within eight categories: operational, governance, economic, innovative and technical, social and behavioural, environmental, process and procedures, and organisational factors. The operational factors encompassed design optimisation, highlighting the importance of designing out waste, waste sorting, and efficient material use. Governance factors emphasised the role of regulations and policies in creating collaboration and partnership mechanisms to promote RCWR. Economic factors underscored the financial incentives, cost challenges, and market demand, while innovative and technical factors addressed emerging technologies, sustainable materials, and modular residential construction. Regarding the social and behavioural factors, an emphasis is placed on the need for education, training, and knowledge-sharing resources. Lastly, organisational factors addressed the influence of client and management commitment and the expertise gap in fostering waste reduction practices. Process and procedure factors explored the opportunity of circularity in achieving RCWR throughout the construction process. Environmental factors are related to reducing the environmental impact of residential construction and promoting the efficient use of finite resources, benefiting both people and the environment.

Understanding the RCWR factors helps policymakers, construction practitioners, and waste management professionals make informed decisions and implement targeted interventions to drive sustainable RCWR practices. The results offer a foundation for future quantitative research to examine the dynamics of these factors and contribute to developing effective RCWR strategies and proactive decision-making in the construction industry. The sample size in this research could limit the generalisability of the findings. Future research could consider a larger sample to improve the results or compare across different regions. As a qualitative study, the findings are subject to potential researcher and participant bias and subjectivity in data analysis and interpretation. Future research could integrate quantitative methods to quantify the influence of the factors and establish correlations or causal relationships to ensure a more objective analysis.

Chapter 5 Examining Factors Influencing Residential Construction Waste Reduction in New Zealand: A PLS-SEM Approach

5.1 Prelude

With New Zealand's rapid growth in residential construction, the corresponding surge in construction waste has ignited a pressing need for effective residential construction waste reduction (RCWR) strategies. This research, therefore, employs partial least squares-structural equation modelling (PLS-SEM) to investigate the factors influencing RCWR and the relationships between these factors in New Zealand. The results from Chapter Four were used to identify the model indicators and hypothesis. Data was gathered using the questionnaire technique, and responses were collected from RCWR experts. The PLS-SEM analysis indicated that factors such as "environmental," "process and procedures," "social and behavioural," and "operational" significantly contribute to RCWR. Notably, the strong path coefficients underscore the crucial role of governance in ensuring effective RCWR. In addition, the "innovation and technical" factors were found to moderately impact the relationship between "governance" and "organisational" factors, offering deeper insights into the intricacies of RCWR dynamics in New Zealand. Implementing the practical measures identified in this study can make valuable strides in promoting RCWR to enhance performance, promote sustainable construction, advance the circular economy, and reduce emissions. These findings can potentially inform strategic development and decision-making processes, guiding future directions in the field of RCWR.

5.2 Introduction

The construction industry is regarded as a significant contributor to environmental degradation due to high energy and resource consumption, and a 25% share of global waste (Gulghane, Sharma, & Borkar, 2023b). The projected global urban population growth is expected to increase by 72% by the year 2050 (Zhang, 2016). Due to the global trend of urbanisation, residential construction has rapidly increased in New Zealand to meet the growing demand. Recent statistics indicate that New Zealand is projected to develop 200,000 new residential units over the next six years, with half of the permits being issued in Auckland (Ministry of Business Innovation & Employment-MBIE, 2023b). The accelerated pace of residential construction is linked to a national 40% increase in construction costs and estimated CW of 4.5 tons per house in Auckland, which is worth $31,000$ of materials (Auckland Council, 2020b; New Zealand Government, 2024).

RCWR has become a critical issue in New Zealand and presents a significant opportunity to achieve sustainable construction and a shift towards a circular economy. Albsoul et al. (2024c) have categorised the benefits of RCWR into four main areas: economic, social, environmental, and sustainable development. The economic benefits lead to cost savings, increased productivity, and improved profitability and competence for companies. From an environmental perspective, benefits include reduced air pollution, noise, and dust levels, as well as relieving pressure on landfills. Social benefits encompass enhancing the city's image, ensuring community satisfaction, and promoting human health. These benefits contribute to accelerating sustainable development and the circular economy shift, which improves sustainable production and consumption of resources (Ding et al., 2016).

While there is a consensus among industry, government, and stakeholders to develop strategies, legislations, and implement practices in RCWR, progress in this area remains slow in New Zealand (Commerce Commission, 2022). Hence, there is an increasing need to examine the factors influencing RCWR in New Zealand. Investigating these factors would provide an opportunity to reevaluate and formulate effective strategies (Laovisutthichai, Lu, & Bao, 2022). Understanding the influencing factors is essential for providing stakeholders with a valuable set of criteria to enhance decision-making in RCWR (Wang, Li, & Tam, 2014). While existing literature has extensively studied factors influencing waste reduction in developed countries, there has been a noticeable lack of emphasis on the residential sector and a comprehensive understanding of the factors in the context of New Zealand. Furthermore, the predominant focus on the design phase and site workers' behaviour towards waste reduction practices has overlooked multiple stakeholder perspectives and the interrelationships among these factors, which are crucial for improving overall performance in RCWR (Liu, Yi, & Wang, 2020).

RCWR is a complicated and multifaceted issue with numerous factors and stakeholders influencing decision-making (Albsoul et al., 2024b, 2024c, 2024d). This complex nature, along with intricate relationships among underlying variables, entails significant, weak, and moderate impacts. These relationships can be multidimensional, posing a challenge in capturing the influence and interdependence of the factors in the model. Additionally, a robust model that can accommodate new insights and variable interactions is required due to the absence of a well-defined theoretical framework. The complexity of the model necessitates an approach capable of evaluating multiple dependent and independent variables simultaneously. Therefore, advanced modelling techniques are essential to provide the decision-making support to navigate the complexity of a problem as RCWR and enable evidence-based policy or strategy formulation (Akter, Fosso Wamba, & Dewan, 2017).

This study employs the partial least squares-structural equation modelling (PLS-SEM) approach to assess the determinants of RCWR in New Zealand, drawing on the research findings by Albsoul et al.

(2024b). PLS-SEM has been frequently employed for exploratory research in construction management that emphasises theory development rather than confirmation, which is particularly valuable when the cause-and-effect relationships between variables have not been explored yet (Zeng et al., 2021). Data was collected using a questionnaire survey. The study's hypotheses assert that RCWR in New Zealand encompasses multidimensional constructs, including operational, social and behavioural, process and procedures, economic, organisational, innovation and technical, governance, and environmental factors, along with their respective indicators.

This research presents a unique perspective on RCWR in New Zealand by evaluating and analysing the factors that contribute to optimising efficiency within the industry. The novel findings expand the quantitative knowledge in this area by providing measurable indicators for RCWR data in New Zealand. The results of this study provide valuable insights for relevant stakeholders, informing strategic development and decision-making processes that could influence the future of sustainable practices in residential construction.

5.3 Theoretical Investigation

5.3.1 Literature review

The aim of this research is to establish and test the theoretical foundation for developing the RCWR framework in New Zealand. To achieve this aim, the following literature review is conducted to synthesise a comprehensive description of existing indicators and support findings in the qualitative framework developed by Albsoul et al. (2024b), and hence, facilitate the formation of relevant indicators for examining the framework constructs and relationships.

5.3.1.1 Operational (OP) indicators

From an operational view, the indicators related to RCWR encompass five parameters, including design optimisation, waste sorting, data capture, logistics and infrastructure, and material sourcing and procurement (Albsoul et al., 2024b). Implementing CW reduction thinking strategy in design operations is significant to RCWR efficiency and has been extensively investigated in prior research (Ajayi & Oyedele, 2018; Baldwin et al., 2009; Carpio et al., 2016; Osmani, Glass, & Price, 2008; Wang, Li, & Tam, 2015). Facilitated collaboration and communication between designers and builders in developing a WMP indicate efficient RCWR outcomes (Llatas & Osmani, 2016).

Moreover, 80% of resource allocation decisions occur during design operations, with over 30% of CW potentially arising from these design choices (Osmani, Glass, & Price, 2008; Yazdi, Fini, & Forsythe, 2021). Despite this, designers perceive that CW is predominantly generated during on-site operations and rarely during design (Albsoul et al., 2024b; Llatas & Osmani, 2016). Thus, educating designers on best practices and raising awareness about the impact of their decisions is imperative to a successful CW reduction (Anitha, Janani, & Banupriya, 2022; Savolainen et al., 2018).

Furthermore, Albsoul et al. (2024d) emphasised the role of designers in understanding the consequences of their design choices and the necessity for client involvement. Wang, Li and Tam (2015) suggested that regulating CW could incentivise designers, given the ambiguity surrounding their role and responsibility in CW reduction, coupled with the lack of material standardisation that diminishes performance. A notable disparity often exists between design specifications and the standard sizes of materials available in the market, leading to increased CW, particularly with custom-designed homes (Albsoul et al., 2024b; Liu et al., 2015; Yazdi, Fini, & Forsythe, 2021). Modular design in residential construction was suggested as an innovative construction method that incorporates cost savings, increased productivity, and CW reduction but limits design customisations and, therefore, market advantage (Yazdi, Fini, & Forsythe, 2021).

Shortage of materials that offer improved end-of-life outcomes or have a reduced environmental impact is addressed to influence design decisions (Albsoul et al., 2024b). Cost and affordability often determine the choice of sustainable materials (Chan & Chan, 2022; Hammad, Haddad, & Figueiredo, 2024). In New Zealand, limited locally sourced materials and compliance with building code standards contribute to challenges in material choices (Albsoul et al., 2024b). Government incentives are needed to encourage local production of materials. Overordering of materials is often influenced by supply chain and logistics issues (Jia et al., 2018). CW reduction could be incorporated as a contractual or procurement requirement, focusing on materials with a high waste profile. Material loss could be avoided by improving the logistics of materials, planning the management of surplus and applying innovative storage and handling practices (Gálvez-Martos et al., 2018).

5.3.1.2 Governance (Gov) indicators

From the governance aspect, compliance with the building code emerges as a critical consideration. Ilal and Günaydın (2017) emphasise that project design, construction, and operation must comply with the building code to meet specific performance requirements. However, compliance complexities can be a significant barrier to sustainability, particularly in achieving CW reduction, as in the case in the US and China (Chi et al., 2020). In RCWR, Albsoul et al. (2024b) suggested that regulatory reforms and amendments in the building code are required to reflect regional differences and facilitate the market of sustainable and recycled materials, pointing out that existing compliance frameworks do not align with sustainable practices and potentially increase costs. Moreover, the role of government is emphasised in fostering regional cooperation and establishing a systematic approach to regional CW management (Albsoul et al., 2024d; Wang, Xie, & Liu, 2022). Such initiatives encourage innovation and enhance environmental governance among enterprises within the region. This multifaceted approach could pave the way for more sustainable building practices, ultimately aligning regulatory requirements with the growing demand for environmental accountability in the construction sector.

While regulations establish a foundational framework for effective CW management, over-reliance on penalty-based approaches may lead to reduced effectiveness of the regulations and increased burdens on management systems (Liu, Yi, & Wang, 2020; Shiers et al., 2014). In contrast, incentive-based policies are deemed more effective in fostering a culture for RCWR (Mahpour & Mortaheb, 2018). Albsoul et al. (2024b) highlighted the need for a higher waste levy in New Zealand to optimise RCWR and suggested that education and awareness, a cost-benefit analysis, and government-led collaborations and partnerships are crucial for successful implementation of RCWR before introducing new regulations.

5.3.1.3 Organisational (OG) indicators

The organisational indicators focus on support from top management, which encourages a positive shift in waste behaviour (Ajayi et al., 2016). The organisational commitment to RCWR can be measured by establishing a strategic plan that sets clear targets for waste reduction (Othman & Saad, 2024b). This echoes research in New Zealand, affirming that having top management support and clear directions is critical to RCWR implementation (Albsoul et al., 2024c). The literature underscores the need for an organisational strategy that addresses the expertise level, including education and work experience in CW reduction (Othman & Saad, 2024b; Suciati, Adi, & Wiguna, 2018). A study investigating CW reduction by design in Egypt emphasised the significance of enhancing technical capabilities for effective communication within design teams and the early involvement of suppliers and contractors (Othman & Saad, 2024b). In addition, the client's commitment to sustainability can influence project requirements and encourage a focus on waste reduction (Bajjou & Chafi, 2022).

Organisations that set targets for RCWR establish roles dedicated to creating training programs to reduce CW influence on the effective implementation of innovation and technology in RCWR practices (Ajayi et al., 2015; Othman & Saad, 2024a). Collaboration and partnerships within the industry drive innovation and inspire others to adopt sustainable practices (Ajayi et al., 2016; Albsoul et al., 2024b, 2024c, 2024d). Government support and assistance in the form of a clear blueprint or best practice references are needed for industry organisations in New Zealand to meet training needs and accelerate innovation (Adafin et al., 2022; Albsoul et al., 2024b). Smaller residential construction companies often lack technical expertise, and external support is necessary to bridge the knowledge gap related to efficient waste reduction practices (Ramos & Martinho, 2021). Additionally, financial challenges and limited internal training programs for waste reduction in residential construction companies may impede the successful implementation of CW reduction strategies (Aslam, Huang, & Cui, 2020; J. Li et al., 2018; Othman & Saad, 2024b).

5.3.3.4 Economic (Ec) indicators

Regarding the economic aspect, the cost of RCWR often outweighs the benefits. Implementing onsite waste sorting, along with the consequent challenges of transportation and storage, necessitates additional labour and resources, resulting in additional costs. Moreover, these challenges are associated with facilitating the recycling and reusing of materials, raising concerns about whether the environmental `benefits outweigh the costs incurred (Ram, Kishore, & Kalidindi, 2020). The lack of robust financial incentives coupled with limited profitability restrict competition and market development for material waste (Huang et al., 2018). Research has indicated that governance interventions, such as government subsidies and tax incentives, can elevate RCWR efforts by improving economic profits (Xiang et al., 2022). In addition, imposing high landfill taxes has been correlated with high levels of waste recovery and low reliance on landfills (Duan et al., 2019; Gálvez-Martos et al., 2018).

5.3.3.5 Process and Procedure (PP) indicators

The construction industry operates predominantly on a project-by-project basis, characterised by short-term contracts and different supply chain designs (Xu, 2020). This operational framework hinders long-term collaborations and investments in standardised processes for information across projects, which are predecessors to implementing a circular business model (Kedir et al., 2024). The transition towards a more circular economy necessitates adopting circular business models, especially in the realm of RCWR (Albsoul et al., 2024). These models play a pivotal role in supporting material take-back schemes, addressing critical infrastructure needs, and engaging in upstream activities vital for unlocking circularity (Oluleye et al., 2022).

Furthermore, integrated design and build models enhance upstream activities and enable planning for successful waste sorting successfully (Lam et al., 2019). Albsoul et al. (2024b) indicated that it is imperative to conduct standard analyses of business processes and enhance the initial processes during the early stages of design and planning in construction projects. Planning for design and construction operations and onsite management approaches practices enhances the responsibility for waste reduction in the supply chain (Rundle, Bahadori, & Doust, 2019). Thus, accessible guidelines on RCWR and collaboration among stakeholders are significant, particularly for smaller-scale builders (Albsoul et al., 2024).

5.3.3.6 Innovative and Technical (IT) indicators

Adopting the right technology in the design and planning of residential construction, such as BIM, 3D printing, and material passports, can significantly reduce CW (Albsoul et al., 2024c). Developing a materials passport system and implementing off-site manufacturing has the potential to enhance waste reduction and efficiency in residential construction (Albsoul et al., 2024b, 2024c; Munaro & Tavares, 2021). However, off-site manufacturing is not widely implemented in smaller-scale projects, and transportation challenges could limit its adoption (Agapiou, 2021; Albsoul et al., 2024b; Wuni, Shen, & Darko, 2022). Constraints such as project size, customisation requirements, training needs, and cost currently restrict the widespread adoption of off-site manufacturing in New Zealand (Albsoul et al., 2024b).

R&D is a crucial element in the aspect of innovation and technology in RCWR (Albsoul et al., 2024b). Research can address technical concerns about the safety and long-term performance of recycled materials, as well as develop markets for modular products, reusable materials, and new building materials (Zhang, Wei, & Zhang, 2023). The government lead to address challenges such as the cost of R&D, along with the need for a system-level approach to supply chains, are essential considerations (Albsoul et al., 2024d; Hasan, Sagar, & Ray, 2023). In addition, compliance requirements can limit the introduction of innovative construction materials (Gharbia et al., 2023). Introducing innovative accreditation and labelling systems can promote information for designers on sustainable practices and enable stakeholders' commitment to RCWR (Albsoul et al., 2024b, 2024d).

5.3.3.7 Social and Behavioural (SB) indicators

Transforming the perception of waste from a mere problem to an opportunity is crucial in fostering positive attitudes towards waste reduction, this shift requires a combined approach of education and incentives (Albsoul et al., 2024b; Liu et al., 2017). The willingness to adopt change in construction operations, particularly regarding waste sorting practices, plays a significant role in actively reducing waste. A comprehensive understanding of the magnitude of the waste issue, alongside the client's awareness of feasible solutions, is crucial in stimulating demand for CW reduction (Bakshan et al., 2017; Wang, Yu, et al., 2019). Albsoul et al. (2024b) revealed that younger workers show a greater willingness to learn about waste reduction compared to older generations, suggesting integrating sustainability and waste reduction into every role within the industry. Moreover, commitment and collective education with exposure to real-life projects contribute to building a culture focused on waste reduction (Gálvez-Martos et al., 2018). Furthermore, peer pressure through showing best practices and mutual learning can be leveraged to drive positive change in construction practices and waste reduction efforts (Albsoul et al., 2024b).

5.3.3.8 Environmental (ENV) indicators

Realising the environmental impacts of residential construction practices is essential for successfully implementing RCWR practices (Albsoul et al., 2024c). Albsoul et al. (2024b) suggested that emphasising the effects of waste on New Zealand's natural beauty and limited resources can encourage positive behaviours towards RCWR. Providing quantified environmental impact through lifecycle information for materials can help individuals make more eco-friendly choices (Albsoul et al., 2024b; Jalaei, Zoghi, & Khoshand, 2021). Additionally, using materials that can be reused or recycled and considering the carbon footprint are effective strategies for reducing environmental impact (Albsoul et al., 2024b; Kabirifar et al., 2020).

The responsibility of construction products manufacturers and suppliers is an effective policy in achieving CW reduction and circular economy but is yet to be developed and implemented in Australia and New Zealand (Albsoul et al., 2024b; Shooshtarian, Maqsood, et al., 2021). Ultimately, the responsibility for CW reduction requires the entire supply chain collaboration, including manufacturers and suppliers, to propose alternative materials with better end-of-life options (Albsoul et al., 2024d; Kabirifar et al., 2020).

5.3.2 Hypothesis and model development

Initially, the lack of understanding of the economic value of waste, limited profitability, and the pressures associated with increased construction costs contribute to the slow advancement in rethinking RCWR practices, shifting business models, and impeding circularity practices (Benachio, Freitas, & Tavares, 2020; Shooshtarian, Maqsood, & Wong, 2024). Higher waste levies and financial incentives are perceived to motivate the adoption of innovative practices and the investment in circularity (Bao, 2023).

H1 (EC->PP): Economic factors have a direct influence on the PP factors.

The contribution of the OP indicators addresses the influence of the lack of reliable waste data on setting measurable RCWR targets and benchmarking progress. This is vital to modelling best practices, unlocking circularity, and supporting sustainable business models. Additionally, the availability of waste infrastructure and logistics influences waste sorting and diversion operations, which are fundamental to circularity (Hossain, Wu, & Poon, 2017; Lam et al., 2019). Early planning and design for RCWR by implementing sustainable procurement practices, specifying materials that hold a circular value, and prioritising RCWR in design drive the contribution of PP to RCWR (Osmani & Villoria-Sáez, 2019; Tazi, Idir, & Fraj, 2021).

H2 (OP -> PP): Operational factors have a direct influence on the PP factors.

The PP category strives to unlock circularity and develop business models that prevent waste from occurring and restore and regenerate its value, from material manufacturing to eliminating landfills. Creating a residential construction system that designs buildings and products focused on circularity involves targeting RCWR and realising the environmental impacts and benefits of residential construction throughout its life cycle (Wang, Wu, et al., 2019; Yahya, Boussabaine, & Alzaed, 2016).

H3 (PP -> ENV): PP factors have a direct influence on the ENV factors.

Realising the environmental benefits and impacts of RCWR will influence change in the SB factors. Recognising the environmental benefits of RCWR increases responsibility and influences a positive shift in the SB factors toward its adoption (Bakshan et al., 2017; Suciati, Adi, & Wiguna, 2018).

H4 (ENV->SB): ENV factors have a direct influence on the SB factors.

The governance category is suggested to have a significant impact on several categories, including IT, EC, SB, and OP. Compliance with building code influence was highlighted in restricting material choices and limiting market development for reuse, recycled materials, and innovative solutions. Government-led initiatives for collaboration and partnership are crucial for supporting organisations in achieving product stewardship accreditation, breaking down industry silos, enhancing awareness and education and promoting shared responsibility (Shooshtarian, Maqsood, et al., 2021). Additionally, government funding for research is necessary to support the private sector in enhancing the level of IT and addressing concerns about the safety and effectiveness of recycled or reused materials, thus increasing confidence in their usage and expanding the market.

Albsoul et al. (2024b) reported that over a third of the experts in RCWR support imposing a higher waste levy to encourage exploring alternative waste disposal methods and improving RCWR practices, such as design optimisation and waste sorting practices, which are directly related to the operational category. Government intervention in implementing financial incentives and waste levies would positively influence the willingness to adopt RCWR and drive companies' behaviour to prioritise and adopt RCWR practices (Liu et al., 2017). Accordingly, the following four hypotheses are introduced to capture the influence of the governance category and relationships.

H5 (GOV->EC): the GOV factors have a direct influence on the EC factors.

H6 (GOV-> IT): the GOV factors have a direct influence on the IT factors.

H7 (GOV->OP): the GOV factors have a direct influence on the OP factors.

H8 (GOV->SB): the GOV factors have a direct influence on the SB factors.

The category of the OG factors addresses the influence of leadership and management commitment to driving education and cultural change in the industry, which is relevant to the SB category. Moreover, the impact of a top-down management approach that mandates adopting RCWR practices and provides the necessary resources and education can create positive peer pressure and willingness to change within the industry (Othman & Saad, 2024b). The level of innovation in RCWR is perceived to be influenced by expertise and training gaps, particularly in smaller-scale residential construction companies. Organisations that set targets for RCWR establish roles dedicated to creating training programs, closing these knowledge gaps and enabling the effective implementation of innovation and technology in RCWR practices (Albsoul et al., 2024b; Venugopal & Ambatipudi, 2023). Hence, the research proposes the following hypotheses that outline the influence of OG.

H9 (OG-> IT): the OG factors have a direct influence on the IT factors.

H10 (OG->SB): the OG factors have a direct influence on the SB factors.

5.4 Research design

Figure 5.1 illustrates the research design employed in this study based on the research aim, including the methodology, data collection, and analytical approaches used to examine the factors influencing RCWR.

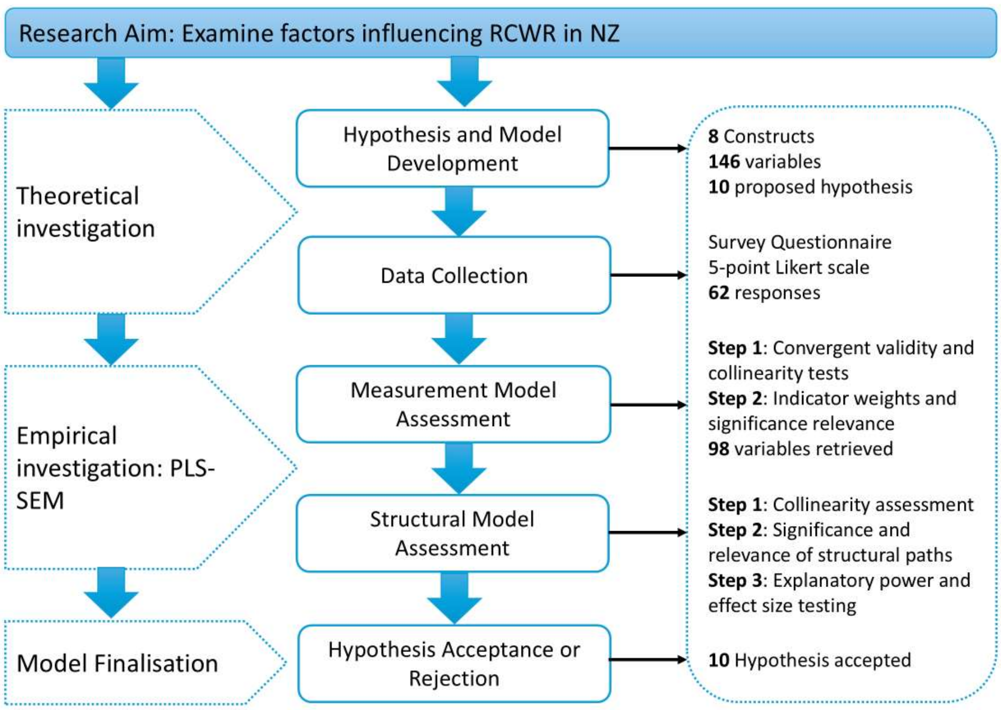

Figure 5.1: Research Design

5.4.1 Data collection and questionnaire design

This research aims to evaluate the importance of factors and provide insights into their interrelationships. To achieve this aim, the collected data will be quantitatively measured, analysed, and validated through PLS-SEM. Thus, the choice for the questionnaire aligns with this objective and a structured questionnaire was designed and administered to investigate the indicators of RCWR in New Zealand. The questionnaire targeted experts in New Zealand to collect empirical data on the variables under investigation. The selected sampling technique was purposeful sampling followed by snowball sampling. To ensure relevant and reliable quantitative data, the criteria for participant recruitment included having i) experience in New Zealand's residential construction sector, ii) a dynamic role in RCWR, and iii) a minimum overall experience of three years.

The questionnaire was divided into three parts. The first section informed potential participants about the research's background, contribution, risks, and benefits. The second part collected information about the participant's role and experience in RCWR. The last part proposed a list of statements specifically designed based on the formative indicators of factors influencing RCWR in New Zealand. The participant assigned each statement a value according to the degree of agreement or disagreement.

The questionnaire design and data collection were internet-based. Internet-based questionnaires are efficient and effective for constructing, collecting, storing, visualising data, and accelerating data analysis due to easier data processing and form management (Cooper et al., 2006; Nayak & Narayan, 2019). Qualtrics is the selected software tool for questionnaire design and data collection. Molnar (2019) highlighted some advantages of Qualtrics, including (i) the ability to customise an intuitive survey; (ii) it could be integrated with other tools for analysing data, eliminating bias, and data presentation; and (iii) being supported by multiple operating systems either web or phone-based for more accessible user experience. A research poster promoting the survey was distributed at industry-related conferences, workshops, and through professional social networks and industry organisations.

A Likert scale of importance that indicates the respondent's degree of agreement or disagreement is selected to reflect the questionnaire's aim (Joshi et al., 2015). The questionnaire aims to measure and understand the participant's opinions and perceptions towards the factors influencing RCWR. Benefits of the Likert scale include fast data collection from a wide range of respondents, high-reliability estimates, and easy comparison with qualitative data (Nemoto & Beglar, 2014). The Likert scale is well-supported by literature on CW management and has been widely applied by researchers such as Hassanain et al. (2018) and Tongo, Adeboye and Oluwatayo (2021). The Likert scale used in this questionnaire is five-point; as the degree of agreement increases, the assigned value increases (1-strongly disagree, 5-strongly agree).

5.4.2 PLS-SEM

SEM is a quantitative technique applied to measure and analyse the relationships among observable variables (Thakkar & Thakkar, 2020). The measurement model and the structural model are the main elements of SEM. The measurement model examines the reliability and validity of the relationship between constructs and variables (Tripathi & Jha, 2018). The structural model demonstrates the relationship between the constructs (Tripathi & Jha, 2018). SEM allows researchers to concurrently model and evaluate complex relationships between several dependent and independent variables (Hair Jr et al., 2021). Following the objectives of the quantitative investigation in this research, SEM is valuable in observing, measuring, and evaluating the influencing factors and the interrelationships among these factors.

The adopted analysis approach is the PLS. The primary objective of PLS-SEM is to explain variations in the model's dependent variables (Hair Jr et al., 2021). PLS-SEM has been noticeably applied more often in all research disciplines and construction management (Tripathi & Jha, 2018). Moreover, PLS-SEM is the preferred approach for exploratory research for theory development (Baig et al., 2020). The *SmartPLS 4.0.2* software was used to examine both the measurement and structural models.

5.5 Results

5.5.1 Respondents' profile

The respondents involved in this research are experts in RCWR from New Zealand. The number of research respondents was sixty-two (62) people, consisting of experts from the residential construction sector, design, government, and RCWR services in New Zealand. The questionnaire was completed online, with 511 distributed surveys. 106 responses were initially received. After eliminating invalid questionnaires, screening, and data imputation, 62 valid responses were retained. Numerous studies have been conducted using the PLS-SEM method with similar sample sizes, like Ahmadabadi and Heravi (2019) and Bamgbade, Kamaruddeen and Nawi (2015) with sample sizes of 48 and 45, respectively. Furthermore, the sample size requirements do not impact the adequacy of the sample in formative PLS-SEM, as suggested by Zeng et al. (2021).

From the perspective of company size (Figure 5.2.a), small to medium enterprises (SMEs) are the majority in New Zealand and represent firms with 6 to 49 employees (Ministry of Foreign Affairs & Trade-MFAT, 2024). SMEs are the largest group in the sample, which is consistent with statistics showing that SMEs are the majority in New Zealand. As shown in Figure 5.2.b, the largest group among the respondents was the residential construction, consisting of 20 participants (32%). This was followed by the RCWR services, with 14 participants (23%). The smallest group in this category was designers, representing 8% of the sample population. Demographic statistics in terms of experience (Figure 5.2.c), the largest group comprised those with more than 20 years of experience in residential construction (32 participants, 52%) and RCWR-related experience (17 participants, 27%). The next group was those with 11 to 15 years of experience in residential construction (14 participants, 23%) and RCWR-related experience (9 participants, 15%). Overall, more than half of the respondents in the sample possess substantial experience, averaging 10 years, in RCWR and residential construction in New Zealand.

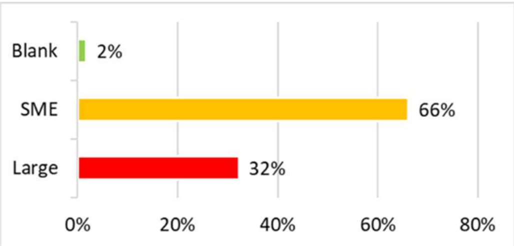

Figure 5.2.a: Company size

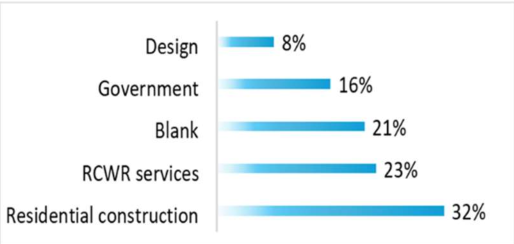

Figure 5.2.b: Company services

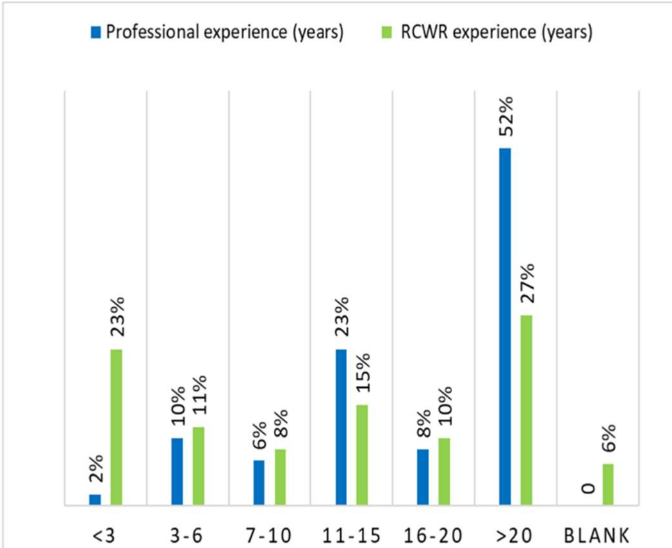

Figure 5.2.c: Participants experience

Figure 5.2: Respondents' profile

The respondents' profile in Table 5.1 is presented regarding educational background, management level, and geographic distribution of experience. Most respondents held high educational degrees, including bachelor's degrees (37%) or postgraduate degrees (Masters, 18% and Doctorate, 8%). Those with other educational levels were 11 participants (18%). Regarding management level, the largest group were those in senior management levels, with 31 participants (50%). The geographic distribution of respondents shows that 66% have relevant experience in regional areas of New Zealand, while 39% reported relevant experience specifically in Auckland. Additionally, 10% indicated experience both in New Zealand and internationally. As a result, the sample reflects a strong population relevant to RCWR, which enhances the validity and generalisability of the research.

Table 5.1: Respondents' profile

Highest degree	
University Bachelor's	37%

Masters	18%
Doctorate	8%
Other (high school, trade certificate, diploma)	18%
Blank	2%
Management level	
Middle management	6%
Senior management	50%
Supervisor/team leader	10%
Blank	3%
Other	31%
Geographic distribution of experience	
Auckland	39%
Regional New Zealand	66%
New Zealand and International	10%
Blank	31%

5.5.2 Measurement model assessment

5.5.2.1 convergent validity and collinearity

The measured constructs of the RCWR model were assessed using the formative measurement model assessment steps. First, a convergent validity test was conducted using SmartPLS. Convergent validity assesses the correlation among the formative indicators in the measurement model to ensure that these indicators effectively represent the construct (Cheah et al., 2018). Subsequently, the redundancy analyses of the measured constructs showed four collinear indicators: OP5.4 and OP5.3 are 0.897, while OP3.4 and OP4.3 are 0.851. Two indicators, OP3.4 and OP5.3, were removed afterwards to avoid redundancy and ensure a meaningful contribution. As a result, all the retained formatively measured indicators demonstrate convergent validity.

In the second step of the assessment procedure, the collinearity in the measurement model was assessed by evaluating the variance inflation factor (VIF) values of the indicators. High VIF values suggest a high level of collinearity. VIF values of 5 or higher indicate collinearity problems, while values between 3 and 5 suggest possible collinearity issues (Hair Jr et al., 2021). In the first run of the PLS algorithm, 33 indicators showed VIF values higher than 5. Since formatively measured indicators need to provide a unique and meaningful contribution, a thorough examination of indicators is needed to determine which to remove (Necmi Kemal Avkiran, 2018; Purwanto, 2021). Accordingly, 13 indicators (OP1.2, OP1.3, OP 1.7, OP1.10, OP2.2, OP2.3, OP2.6, OP3.6, OP4.2, OP4.4, OP5.5, OP5.7, and PP2.7) were eliminated from the measurement model due to repetition issues. Upon running the algorithm again, potential collinearity problems were uncovered, leading to further investigation into indicators with VIF values between 3 and 5. Subsequently, 10 more indicators (OP1.11, OP2.1, OP3.2, OP3.3, OP3.8, OP5.4, OP5.8, PP1.5, PP3.4, PP3.6) were excluded for further repetition issues, resulting in the removal of 25 indicators from the measurement model while retaining 121 for additional testing.

5.5.2.2 Indicator weights and significance relevance

This step involves examining each indicator's relative contribution to forming the construct. Hence, the significance and relevance of the indicator's outer loading weights must be assessed by running the bootstrap function. Streukens and Leroi-Werelds (2016) advised to run a 10,000 bootstrap sample to reduce bias and achieve robust and reliable confidence intervals. Indicator weight is significant when the outer loading exceeds 0.5 (>0.5) (Necmi K Avkiran, 2018; Hair Jr et al., 2021). The greater the weight of the significant indicator, the more relevance and contribution to the construct is perceived. For indicators with nonsignificant weights but indicator loading is more than or equal to 0.5 (≥0.50), then the indicators are considered relevant. However, formative indicators that are nonsignificant and have an outer loading of less than 0.5 (<0.5) should be considered for removal as it does not necessarily indicate poor contribution to the construct.

Results from the bootstrapping process revealed that 48 indicators were significant and relevant. The remaining 73 indicators, which were not significant, were further examined for their outer loading values. Of these 73, 15 indicators demonstrated satisfactory loadings, whereas 58 suggested poor contribution to the constructs. In such cases, researchers recommend exercising caution when deleting formative indicators, as it depends on whether all indicators meaningfully capture the construct rather than solely relying on statistical outcomes (Afthanorhan, 2014; Sarstedt et al., 2014). Consequently, all indicators were reviewed and evaluated for potential removal. As a result, 23 indicators were removed due to meaning redundancy, while 35 were retained. A total of 98 indicators are concluded to show satisfactory levels of quality after being assessed for reliability and validity in the RCWR PLS-SEM model, as shown in Table 5.2.

Table 5.2: Indicator weights and significant relevance in the measurement model

Indicator	VIF	Outer weights	Outer loadings	P values
EC1	1.634	-0.317	-0.117	0.65
EC11	1.215	0.772	0.846	0
EC12	1.218	0.02	0.381	0.2
EC4	1.231	0.392	0.398	0.121
EC5	2.087	-0.084	0.267	0.35
EC8	1.508	0.299	0.363	0.169
EC9	1.18	0.156	0.381	0.129
ENV1	1.741	0.362	0.691	0
ENV2	1.702	0.06	0.532	0.008
ENV4	1.351	0.219	0.631	0.003
ENV5	1.185	0.295	0.61	0.001
ENV7	1.319	0.187	0.613	0.008
ENV8	1.442	0.38	0.75	0
GoV1	1.813	0.315	0.76	0
GoV10	1.785	0.106	0.515	0.003
GoV14	1.46	0.377	0.609	0
GoV16	2.058	0.223	0.622	0.001

GoV17	1.666	-0.215	0.417	0.031
GoV3	1.805	0.291	0.578	0.02
GoV5	2.315	0.016	0.5	0.026
GoV6	2.004	0.288	0.622	0.002
GoV7	1.245	0.091	0.339	0.106
GoV9	1.309	0.093	0.436	0.015
IT1	2.393	0.31	0.739	0
IT10	1.831	0.355	0.579	0.008
IT11	1.528	0.207	0.483	0.062
IT12	2.506	0.014	0.594	0.01
IT2	2.627	-0.252	0.491	0.017
IT3	2.112	0.525	0.731	0
IT4	1.729	0.273	0.329	0.084
IT5	2.379	-0.201	0.407	0.104
IT6	2.258	0.243	0.571	0.004
IT7	1.889	0.094	0.29	0.221
IT8	2.272	0.048	0.577	0.006
IT9	2.641	-0.01	0.503	0.013
OG1	1.656	-0.046	0.528	0.013
OG2	1.682	0.209	0.689	0.001
OG3	1.322	0.122	0.521	0.006
OG4	1.408	0.191	0.387	0.038
OG5	1.552	0.383	0.695	0.002
OG6	1.359	-0.264	0.108	0.601
OG7	2.029	0.16	0.652	0.001
OG8	1.826	0.272	0.634	0.001
OG9	1.565	0.32	0.713	0
OP1.1	1.511	0.11	0.445	0.004
OP1.4	1.383	-0.164	0.18	0.266
OP1.5	1.827	-0.231	0.357	0.032
OP1.6	1.608	0.057	0.298	0.065
OP1.8	1.337	-0.057	0.026	0.898
OP1.9	1.33	0.38	0.375	0.026
OP2.4	1.78	0.199	0.454	0.003
OP2.5	1.666	0.2	0.373	0.045
OP2.8	1.627	-0.01	0.382	0.006
OP2.9	1.839	-0.076	0.494	0.014
OP3.1	1.244	0.114	0.038	0.849
OP3.5	1.517	0.018	0.137	0.414
OP3.9	1.509	-0.049	0.091	0.568
OP4.1	1.483	0.18	0.328	0.059
OP4.5	1.474	0.14	0.501	0.01
OP4.7	1.466	0.463	0.576	0
OP4.9	1.646	0.354	0.549	0.003
OP5.2	1.281	0.287	0.445	0.007
OP5.6	1.489	0.13	0.469	0.001
PP1.1	2.186	0.306	0.573	0.001
PP1.2	2.19	-0.105	0.445	0
PP1.3	2.104	-0.165	0.463	0.014
PP1.4	2.039	0.181	0.545	0.001
PP1.6	1.839	0.128	0.628	0
PP1.7	1.951	-0.108	0.067	0.715
PP1.8	2.063	0.007	0.354	0.005
PP1.9	2.385	0.134	0.606	0.002

PP2.1	1.952	-0.049	0.508	0
PP2.2	2.494	-0.125	0.568	0
PP2.3	1.353	-0.019	0.199	0.188
PP2.4	2.508	0.319	0.778	0
PP2.5	2.203	0.186	0.587	0.001
PP2.6	2.255	0.073	0.514	0.001
PP2.8	2.462	0.077	0.606	0
PP2.9	2.434	0.151	0.619	0.001
PP3.1	2.032	0.025	0.493	0
PP3.2	2.441	0.06	0.552	0.001
PP3.3	2.154	0.188	0.614	0.001
PP3.5	2.94	0.19	0.507	0
SB1	1.779	0.209	0.407	0.035
SB10	1.806	0.31	0.668	0
SB11	1.547	0.217	0.542	0.004
SB12	2.325	0.034	0.657	0.001
SB13	2.424	-0.073	0.529	0.001
SB14	2.337	0.331	0.617	0
SB15	1.931	0.179	0.617	0
SB2	2.925	0.008	0.512	0.012
SB3	2.059	-0.186	0.289	0.106
SB4	1.776	0.393	0.636	0.002
SB5	1.755	0.027	0.451	0.017
SB6	1.811	-0.021	0.503	0.031
SB7	1.478	0.064	0.466	0.012
SB8	1.468	0.038	0.13	0.432
SB9	1.707	0.118	0.464	0.01

5.5.3 Structural model assessment

5.5.3.1 Collinearity assessment

This step aims to assess the relationships between constructs in the structural model to avoid bias and potential collinearity issues. Similar to the collinearity assessment in the measurement model, VIF values greater than 5 indicate critical collinearity issues, while VIF values between 3 and 5 indicate possible collinearity (Hair Jr et al., 2021; Purwanto, 2021). After running the PLS algorithm, all VIF values were below 3, indicating no collinearity issues (see Table 5.3).

Table 5.3: VIF values in the structural model

Hypothesis	
EC -> PP	1.419
ENV -> SB	2.198
Gov -> EC	1
Gov -> IT	1.9
Gov -> OP	1
Gov -> SB	2.63
OG -> IT	1.9
OG -> SB	1.999
OP -> PP	1.419
PP -> ENV	1

5.5.3.2 Significance and Relevance of the Structural Model Relationships

As part of the analysis process, after calculating VIF within the structural model, a bootstrap analysis is run to test the statistical significance of the path coefficients for hypothesis testing. Like the formative indicators, a path coefficient with a P value less than 0.05 is considered statistically significant. However, it is vital to assess the relevance of path coefficients. Path coefficients are considered relevant when their original sample values (O) fall between -1 and +1 (Hair Jr et al., 2021). Referring to Table 5.4, only five path coefficients show significance (ENV -> SB, Gov -> EC, Gov -> OP, OP -> PP, PP -> ENV). However, all path coefficients fall within a satisfactory range (-1/+1) and are, therefore, relevant.

Table 5.4: Structural significance and relevance for path coefficients

H	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values
EC -> PP	0.051	0.059	0.111	0.465	0.642
ENV -> SB	0.493	0.459	0.202	2.436	0.015
Gov -> EC	0.51	0.653	0.09	5.681	0
Gov -> IT	0.417	0.415	0.349	1.196	0.232
Gov -> OP	0.822	0.892	0.038	21.822	0
Gov -> SB	0.365	0.322	0.211	1.733	0.083
OG -> IT	0.392	0.459	0.352	1.112	0.266
OG -> SB	0.152	0.228	0.246	0.618	0.536
OP -> PP	0.852	0.879	0.087	9.779	0
PP -> ENV	0.854	0.895	0.032	26.981	0

5.5.3.3 Explanatory Power and Effect Size

Hair Jr et al. (2021) recommended examining the explanatory power and effect size to fully interpret the significance and relevance of the model. This step involves examining the coefficient of determination (R^2) of the endogenous constructs and the f^2 effect size of the predictor constructs. The R^2 value is an indicator of the model's explanatory power, which assesses the proportion of variance in the endogenous constructs that is explained by the exogenous constructs in the model (Becker, Rai, & Rigdon, 2013). The R^2 can be interpreted based on general guidelines, with values of 0.75, 0.50, and 0.25 considered substantial, moderate, and weak, respectively. As shown in Table 5.5, the R^2 values of ENV, PP, OP, and SB are considered substantial, which indicates that those constructs explain at least 70% of the variance in the dependent variable. The R^2 value for IT and EC can be considered moderate and weak, explaining more than 50% and 20% of the dependent variable's variance, respectively.

Table 5.5: Explanatory power R^2 test results

Construct	R^2	Sample mean (M)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values
EC	0.26	0.435	0.105	2.487	0.013
ENV	0.729	0.801	0.056	13.021	0
IT	0.552	0.741	0.068	8.061	0
OP	0.676	0.797	0.059	11.475	0
PP	0.777	0.851	0.045	17.36	0
SB	0.828	0.888	0.034	24.051	0

The effect size (f2) is primarily used to explain which indicators have the most influence on the construct's R^2 value. The f^2 value is expected to follow the same order rank as the path coefficient, with values larger than 0.35 being interpreted as having a substantial effect on fitting the model and values less than 0.02 as weak (Famiyeh, 2017). The ranking results are illustrated in Table 5.6. The structural paths PP -> ENV, OP -> PP, Gov -> OP, OG -> SB, and EC -> PP are consistent and hence significant and have a substantial effect and contribution to the model. However, the rank order for ENV -> SB, Gov -> EC, Gov -> SB, Gov -> IT, and OG -> IT is slightly different and should be interpreted regarding R^2.

For instance, the path coefficient for Gov -> SB (0.365) suggests a moderate direct effect of Gov on SB, whereas the f^2 value (0.295) indicates that Gov has a substantial effect size, meaning it contributes significantly to explaining SB. This is reinforced by a robust R^2 value of 0.828, suggesting that the model's predictors, including Gov, effectively account for most of the variance in SB. The same case applies to ENV -> SB. Conversely, the path coefficient of Gov -> EC (0.51) suggests a strong direct influence with a substantial effect of Gov on EC (f^2= 0.351). However, the overall explanation for EC is only 26%, which is considered weak statistically. However, practically, it is supported by the exploratory research in New Zealand by Albsoul et al. (2024b). The case of Gov -> IT and OG -> IT yields similar interpretations. However, the R^2 value for IT suggests a moderate to substantial effect, indicating that it is well explained by Gov and OG.

Table 5.6: Rank order check

H	f^2	H	Path Coefficients
PP -> ENV	2.695	**PP -> ENV**	0.854
OP -> PP	2.295	**OP -> PP**	0.852
Gov -> OP	2.082	**Gov -> OP**	0.822
ENV -> SB	0.642	**Gov -> EC**	0.51
Gov -> EC	0.351	**ENV -> SB**	0.493
Gov -> SB	0.295	**Gov -> IT**	0.417
Gov -> IT	0.204	**OG -> IT**	0.392
OG -> IT	0.18	**Gov -> SB**	0.365
OG -> SB	0.067	**OG -> SB**	0.152
EC -> PP	0.008	**EC -> PP**	0.051

5.5.3.4 Final model

The model fit indices, including R^2 and f^2, are crucial in determining the robustness of the model. The testing results of VIF, R^2, f^2, and path coefficients indicate that the model adequately captures the variance in RCWR constructs, with the formative indicators providing a comprehensive representation of RCWR. The results support the acceptance of all proposed hypotheses and suggest a substantial influence for the OP, SB, ENV and Gov. The final PLS model in Figure 5.3 includes formative indicators of the factors influencing RCWR in New Zealand.

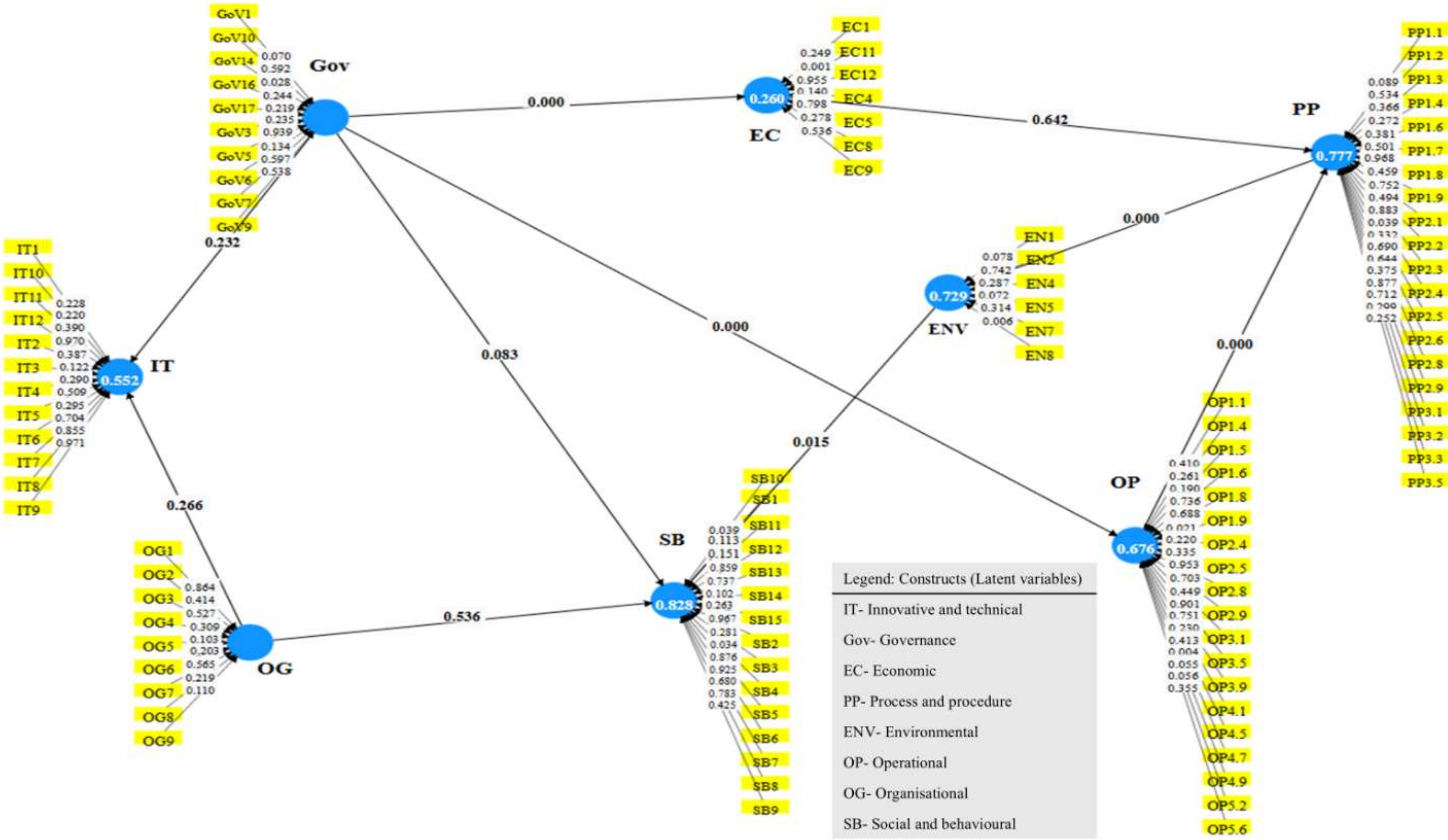

Figure 5.3: The developed RCWR model

5.6 Discussion

The results revealed that OG and Gov constructs are primary drivers of successful RCWR outcomes. Since these constructs drive other variables, they represent critical areas for strategic focus. For instance, decision-makers can focus on improving the OG and Gov indicators to create ripple effects throughout the system. A critical evaluation of the Gov aspect is essential to ensure effective RCWR measures. The findings suggest that government interventions or strategies should focus on reviewing the building code and fostering collaboration and partnerships among RCWR stakeholders. The relationship between Gov and EC is based on creating an economic value for waste, providing financial incentives, and investing in waste infrastructure to support the market for RCWR. These relationships highlight the profit-oriented characteristic of the residential construction industry in New Zealand. The industry predominantly comprises small-scale companies, which face higher risks and limited profitability but are likely to benefit from incentives and subsidies.

However, the OP aspect highlights the performance challenges facing business models seeking to transition their processes into more standardised operations due to the availability and accessibility of waste infrastructure. The results reinforce the hypothesis and previous literature on the OP aspects of RCWR regarding the significance of early planning and design (Llatas & Osmani, 2016; Wang, Li, & Tam, 2015). An interesting finding for New Zealand is the need for councils to provide information about the availability of waste infrastructure to local construction companies. This indicates a strive for change within the industry; however, there is a pressing need for reliable waste data and infrastructure that supports and facilitates decision-making.

The emphasis on OP, ENV, and PP reflects a keenness for partnerships aimed at modelling and advocating best practices. The findings indicate a keen interest in gleaning insights from companies with circular business models or innovative solutions, particularly smaller-scale developers. The ENV aspect underscores the need to take accountability throughout the entire supply chain to instigate change in SB by incorporating sustainability roles within the residential construction sector. Thus, providing specialised training for site supervisors can effectively facilitate the implementation of on-site waste reduction strategies, which seems consistent with the findings of Gálvez-Martos et al. (2018) in Europe.

The aspect of IT is influenced by the relationships with Gov and OG. Government regulations, along with management support and research funding, play a crucial role in driving innovation and overcoming technical limitations. Government involvement in initiating material take-back programs can facilitate efforts to RCWR, leading to improved overall compliance and performance. The connection between innovation, regulation, and management support confirms the proposed hypothesis and is a prominent theme in existing literature, as evidenced by Rennings and Rammer (2011), Ajayi et al. (2015) and Teo and Loosemore (2001).

5.7 Conclusion

This study adopted the PLS-SEM to investigate the factors influencing RCWR and the relationships between these factors in New Zealand. A questionnaire survey was designed and administered to collect data from relevant experts in New Zealand. The study's scientific rigour was strengthened by analysing the formatively measured constructs and their relationships. The results suggest that it is important for government interventions regarding RCWR to focus on reviewing building codes, promoting collaboration among stakeholders, providing financial incentives, and investing in waste infrastructure. Local companies should also prioritise early planning and design, access to waste infrastructure information, and accountability throughout the supply chain. Therefore, it is crucial to facilitate partnerships and encourage best practices, especially for smaller-scale developers. The interaction between innovation, regulations, and management support is critical in driving changes and improving performance.

Additionally, the study emphasises the significance of addressing various factors to achieve sustainable RCWR. It offers valuable insights into the factors and connections impacting RCWR. By using PLS-SEM to analyse and validate empirical findings related to RCWR performance in New Zealand, the study contributes to the RCWR literature. It offers new perspectives, particularly concerning the link between government interventions, environmental awareness, and operational performance, which can aid in optimising performance, developing strategies, and formulating policies in the field of RCWR.

Future studies on RCWR can focus on formulating alternative hypotheses based on different conceptualisations and categorisations of the factors and utilise different statistical methods instead of PLS-SEM. Although using small sample sizes does not necessarily constrain PLS-SEM, a larger sample size could offer a more comprehensive perspective for exploring different measuring instruments, comparing various models, and improving result generalisability. Moreover, conducting research incorporating the formative indicators to establish criteria for a decision-making framework could provide groundbreaking insights into RCWR performance and strategy directions in New Zealand and beyond.

Chapter 6 MCDM Framework for Residential Construction Waste Reduction in New Zealand: A Fuzzy-DEMATEL Fuzzy-TOPSIS Approach

6.1 Prelude

The optimisation of RCWR is becoming increasingly challenging due to the involvement of multiple stakeholders and complex influencing factors. This research aims to tackle this issue by exploring the interrelationships among such influencing factors and assessing their relative significance within a decision-making model. The developed model in Chapter Five was used as the criteria and indicators for this framework. The research employed a MCDM framework, utilising a focus group workshop for the data collection and validation. The analysis integrated the fuzzy DEMATEL method with the fuzzy TOPSIS approaches, facilitating a comprehensive evaluation of decision criteria and interrelations. The results showed that environmental factors held the highest rank, while governance factors exhibited a significant influence and impact on other RCWR factors. The research further put forward strategies to showcase the practical applicability and validity of the proposed MCDM framework. These findings have important implications for New Zealand's planning and development initiatives in RCWR, aligning with relevant SDGs and fostering a circular economy and sustainable built environment. This research will empower decision-makers in RCWR to create priority-based strategies for investment and resource allocation.

6.2 Introduction

The residential construction industry is rapidly developing worldwide. The current rate of material consumption, coupled with increasing population demand for residential construction, presents challenges to the sustainability of future cities and the built environment. The building sector accounts for nearly half of global annual resource usage and generates up to 40% of total annual waste in Europe, Australia, and New Zealand (Albsoul, Doan, & GhaffarianHoseini, 2024; Dorignon et al., 2024).

Amid growing concerns over increased CW and resulting economic and environmental costs, embracing the principles of RCWR can serve as a sustainable and impactful approach. At its core, RCWR aims to foster a circular economy and promote sustainability within the construction industry (Albsoul et al., 2024c). Furthermore, RCWR contributes to the United Nations-UN (2015) SDGs 11 and 12 to “make cities and human settlements inclusive, safe, resilient, and sustainable” and “ensure sustainable consumption and production patterns”, respectively. The majority of developing countries, such as the UK, the European

Commission, and New Zealand, have implemented CW-related policies and targets to align with the commitment to achieve the UN SDGs (Elias, 2022; Fei et al., 2021; Ogunmakinde, Egbelakin, & Sher, 2022).

While some progress has been made, decision-making has become more challenging in RCWR owing to present urbanisation rates and residential construction demand, socioeconomic issues, and global environmental impacts (Albsoul et al., 2024c). The complexity in decision-making is due to the requirements to manage various stakeholders' priorities and the multi-faceted criteria for factors influencing RCWR (Goulart Coelho, Lange, & Coelho, 2017). Hence, the need to control these requirements by forming a decision-making framework becomes prominent.

The fundamental need for decision-making tools is to establish a structural framework that allows an integrated and objective approach to the evaluation of complex variables (Goulart Coelho, Lange, & Coelho, 2017). Traditional decision-making approaches often fail to address the multifaceted nature of the CW systems as numerous criteria must be considered simultaneously, and interdependencies between factors can significantly influence outcomes (Roy, Rautela, & Kumar, 2023; Zhu, Meng, & Zhang, 2021). Additionally, Kim, Nguyen and Luu (2020) suggested exploring the varied perspectives of project stakeholders to create performance-based decision-making frameworks for CW management.

Extensive research has been conducted on performance indicators using different CW quantification methods to enhance site planning and guide reduction practices, as demonstrated by studies in New Zealand (Albsoul, Doan, & GhaffarianHoseini, 2024; Domingo & Batty, 2021), the US (Bakshan et al., 2017), and Spain (Sáez, Porras-Amores, & del Río Merino, 2015; Solís-Guzmán et al., 2009). Quantification modelling techniques for CW reduction are typically hindered by data availability and quality and do not provide a comprehensive view of other factors or adequately address the interests of various stakeholders (Albsoul et al., 2024c). Effective planning for CW should integrate the interests of multiple stakeholders and facilitate interactions among them (Wang, Wu, & Luo, 2021).

Literature suggests several approaches to developing performance-oriented decision-making frameworks for CW strategy development and planning depending on the focus of the assessment criteria. For example, Llatas et al. (2021) focused on the environmental alternatives using the LCA approach, whereas Penteado and Rosado (2016) developed a framework to assess CW recycling strategies. Other approaches assessed the cost-benefit criteria to evaluate the economic aspects of CW, such as Tu et al. (2023) and Tseng et al. (2021). In addition, while the role of digital tools such as BIM in improving decision-making for RCWR at the design stage has also been widely researched (Liu et al., 2015), BIM integration for RCWR presents accessibility challenges due to the training and expertise requirements.

To enhance the performance-based planning method for assessing RCWR, it is essential to involve a diverse range of stakeholders, each bringing unique interests and priorities. Additionally, implementing comprehensive criteria will create a more robust evaluation process. Existing literature suggests that utilising a MCDM approach can be particularly beneficial in the RCWR context (Goulart Coelho, Lange, & Coelho, 2017). MCDM involves finding the most optimal option from multiple assessment criteria and has been praised for its flexibility and ability to consider all criteria and priority aspects simultaneously (Ghaleb et al., 2020). The MCDM approach has been applied to evaluate the factors influencing waste generation in high-rise residential buildings (Nezhaddehghan, Ansari, & Banihashemi, 2023), and also has been used to evaluate the sustainability performance of different group housing systems (Bhyan, Shrivastava, & Kumar, 2023).

Although MCDM has been applied in different contexts related to CW, no study has exclusively applied the methodology to rank and weight factors influencing RCWR. This research, therefore, aims to validate the practicality of the RCWR framework developed by Albsoul et al. (2024a) while balancing the diverse interests of the relevant stakeholders in New Zealand. The research objectives are (i) to prioritise and rank the RCWR indicators to improve RCWR performance in New Zealand and (ii) to balance the diverse interests of relevant decision-makers.

6.3 Methods

The development of an MCDM framework generally involves three key stages (Adem Esmail & Geneletti, 2018). The first stage defines the objective, identifies parameters, and organises the decision-making system (i.e., involves formulating the criteria and outlining the alternatives). The second stage focuses on analysis, which includes gathering data from decision-makers to assess the criteria and evaluate the alternatives. The final stage involves interpreting and validating the framework.

This study's MCDM framework aims to identify the aspects and factors that have a significant influence on RCWR optimisation in New Zealand. To achieve this aim, the following objectives were set: (i) to balance the diverse interests of all stakeholders involved in the RCWR decision-making process, (ii) to rate and weight the aspects and their related factors based on their level of influence and relationships in optimising RCWR in New Zealand. Accordingly, the structure of the MCDM framework includes four levels: (i) 'aim' (ii) 'aspects' – i.e., operational (OP), organisational (OG), social and behavioural (SB), innovative and technical (IT), economic (EC), environmental (ENV), process and procedure (PP), and governance (Gov), (iii) 'factors' – i.e., 98 indicators, and (iv) 'strategy development'. Also, the 'aspects' and 'factors' levels are presented in Appendix B.

A focus group workshop was selected as the data collection approach for this research. A prominent feature of the focus group technique is facilitating idea generation and understanding conflicting interests among participants through extensive deliberative discussions, ultimately reaching a consensus (Aigwi et al., 2022). The Focus group technique has been used frequently in construction management research for data collection (Liang, Leung, & Cooper, 2018) and validation (Hijazi et al., 2021). As the decision-making process involves trade-offs among factors and relationships due to human subjectivity, various weighting and ranking techniques must be considered when applying the MCDM approach. Therefore, it is essential to apply techniques that can integrate subjective uncertainties while ranking priorities and interpreting relationships.

According to Yazdi et al. (2020), the most widely cited papers often use mixed approaches. Combining multiple mathematical techniques is recommended to address the limitations of each method (i.e., qualitative and quantitative) and improve objectivity and accuracy when evaluating multiple criteria (Jato-Espino et al., 2014). Therefore, this study adopts a mixed approach, combining the fuzzy technique for order preference by similarity to ideal solution (TOPSIS) and the fuzzy decision-making trial and evaluation laboratory (DEMATEL) techniques, which will be further elaborated on in the following sections. The TOPSIS has essential role in the ranking process but assumes that the criteria are independent. In contrast, DEMATEL complements this limitation by revealing the visual cause-and-effect relationships among criteria. This dual capability is fundamental for decision-makers, as it guides the identification of strategic advantages within complex decision-making frameworks.

6.3.1 Data collection- focus group

A focus group workshop was conducted in Auckland, New Zealand, on Friday, June 7th, 2024, from 9:00 a.m. to 12:00 p.m. The workshop's title was *"A Decision-Making Framework for Residential Construction Waste Reduction (RCWR) in New Zealand."* Ten relevant RCWR decision-makers were involved in the focus group workshop, and their profiles are summarised in Figure 6.1 and Table 6.2 The decision-makers were organised into three collaborative groups for enhanced discussion and input: *Group A* - red, consisting of 3 experts; *Group B* - green, also with 3 experts; and *Group C* - blue, which included 4 experts. Each group was supported by a dedicated facilitator to guide the conversation effectively.

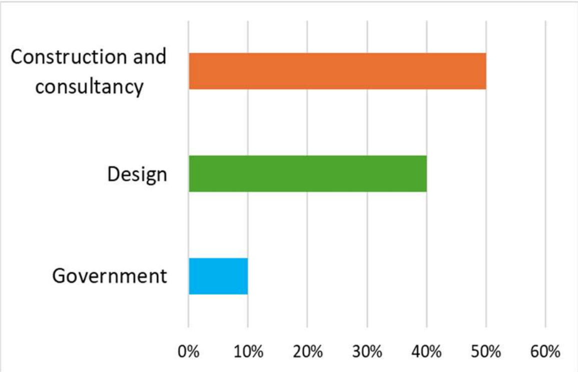

Figure 6.1.a: Company services

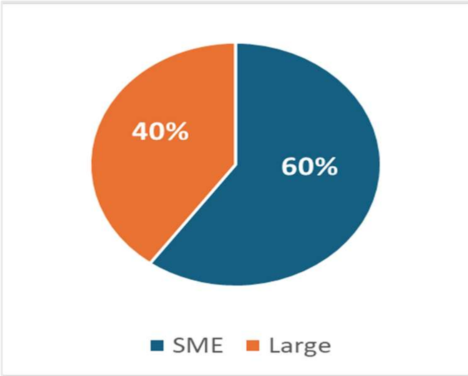

Figure 6.1.b: Company size

Figure 6.1: Experts' characteristics

The experts were purposefully selected based on specific criteria that include a minimum of three years of experience in residential construction and a role relevant to RCWR. The stakeholder groups in the sample included the 'construction and consultancy professionals' (5 experts), 'designers' (4 experts) and 'government representatives' (1 expert), respectively (see Figure 6.1.a and 6.1.b). The decision-makers represented both large enterprises and small to medium-sized enterprises (SMEs), which enhanced the robustness of the sample and provided valuable insights into their characteristics. Larger companies bring ample resources and a structured decision-making process, while smaller companies offer flexibility and a strong ability to adapt to changes. This diversity enriches the overall understanding of decision-making in the business landscape (Sen et al., 2023).

From Table 6.1, 50% of experts have 16 years or more of relevant experience in residential construction, while 60% have six years or less relevant experience in RCWR. This indicates that RCWR is an emerging field in New Zealand with growing interest within the industry. The senior and supervisory levels comprise 90% of the sample, suggesting that the data originates directly from decision-makers. The educational level of experts was evenly distributed, with 50% holding a university degree, reflecting diverse educational backgrounds across the group.

Table 6.1: Experts' characteristics

Experience (years)	Residential construction experience	RCWR experience
<3	0	30%
3-6	30%	30%
7-10	10%	10%
11-15	10%	10%
16-20	20%	10%
>20	30%	10%

Management level	Senior	50%
	Supervisory	40%
	Other	10%
Education level	Bachelor's	30%
	Masters	20%
	Other	50%

6.3.2 Data analysis techniques

6.3.2.1 Fuzzy TOPSIS

The fuzzy TOPSIS is an MCDM technique designed to evaluate and rank the best solution while addressing the uncertainty and vagueness commonly encountered in real-world decision-making scenarios (Shamsuzzoha, Piya, & Shamsuzzaman, 2021). Incorporating fuzzy logic allows experts to express preferences and judgments in linguistic terms, which are then converted into fuzzy numbers (Franco, 2014). The fuzzy TOPSIS is valuable when precise numerical data is challenging to obtain, and subjective assessments play a critical role (Taylan et al., 2014). In this research, fuzzy TOPSIS was employed to weigh and rank the aspects and factors. Table 6.2 presents the fuzzy scale and related linguistic terms used in this technique.

Table 6.2: Fuzzy TOPSIS scale

Likert scale	Fuzzy number			Linguistic term
1	0.1	0.1	2.5	Very Low (VL)
2	0.1	2.5	5	Low (L)
3	2.5	5	7.5	Medium (M)
4	5	7.5	10	High (H)
5	7.5	10	10	Very High (VH)

The fuzzy TOPSIS technique was adapted from Awodi et al. (2023) and Maghsoodi and Khalilzadeh (2018) for E number of experts/decision-makers, and a decision-making problem with m aspects and n alternatives: A_i= (i=1,….,n). Accordingly, the following steps were performed:

Step 1: The weights of aspects (criteria) and ratings of factors (alternatives) were calculated using the equations (1) and (2)

Average Rate: $\tilde{x}_{ij} = \frac{1}{E}\left[\tilde{x}_{ij}^{1}(+)\tilde{x}_{ij}^{2}(+)\dots(+)\tilde{x}_{ij}^{E}\right]$ (1)

Average Weight: $\widetilde{w}_{j} = \frac{1}{E}\left[\widetilde{w}_{j}^{1}(+)\widetilde{w}_{j}^{2}(+)\dots(+)\widetilde{w}_{j}^{E}\right]$ (2)

Where $\tilde{x}_{ij}^{E}$ and $\widetilde{w}_{j}^{E}$ are the rating and the importance weight of j^{th} criterion (c_j)

Step 2: The fuzzy decision matrices of the criteria and the alternatives $\widetilde{D}$ were constructed using the equations (3) and (4) where $\tilde{x}_{ij} = (a_{ij}, b_{ij}c_{ij})$ and $\widetilde{w}_j = (w_{i1}, w_{i2}, w_{i3})$.

$$\widetilde{D} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \cdots & \tilde{x}_{mn} \end{bmatrix} \quad (3)$$

$$\widetilde{W} = [\widetilde{w}_1, \quad \widetilde{w}_2, \quad \dots, \quad \widetilde{w}_n] \quad (4)$$

Step 3: The normalised fuzzy decision matrix $\tilde{R}$ was constructed using equations (5), (6), and (7) where $c_j^* = \max_i c_{ij}$ and $a_j^- = \min_i a_{ij}$

$$\tilde{R} = [\tilde{r}_{ij}]_{m \times n} \quad (5)$$

Benefit criteria: $\tilde{r}_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right)$ (6)

Cost criteria: $\tilde{r}_{ij} = \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{c_{ij}}\right)$ (7)

Step 4: The weighted normalised fuzzy decision matrix $\widetilde{\mathrm{V}}$ was obtained using equation (8)

$$\widetilde{\mathrm{V}} = [\tilde{\mathrm{v}}_{\mathrm{ij}}]_{\mathrm{m \times n}}, \mathrm{i} = 1,2, \dots, \mathrm{m}, \mathrm{j} = 1,2, \dots, \mathrm{n} \quad \text{where } \tilde{v}_{ij} = \tilde{r}_{ij}(x)\widetilde{w}_j \quad (8)$$

Step 5: The fuzzy positive-ideal solution (FPIS, A*) and fuzzy negative-ideal solution (FNIS, A−) were calculated following equations (9) and (10) Where $\tilde{v}_j^* = (1,1,1)$ and $\tilde{v}_j^- = (0,0,0), j = 1,2, \dots, n$

$$A^* = (\tilde{v}_1^*, \tilde{v}_2^*, \dots, \tilde{v}_n^*) \quad (9)$$

$$A^- = (\tilde{v}_1^-, \tilde{v}_2^-, \dots, \tilde{v}_n^-) \quad (10)$$

Step 6: The distances from each alternative to the A* and A− and the closeness coefficient CC_i were computed using the following equations: (11), (12), and (13)

$$d_i^* = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^*), i = 1,2, \dots, m \quad (11)$$

$$d_i^- = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^-), i = 1,2, \dots, m \quad (12)$$

$$\mathrm{CC_i} = \frac{\mathrm{d_i^-}}{\mathrm{d_i^*} + \mathrm{d_i^-}}, \mathrm{i} = 1,2, \dots, m \quad (13)$$

6.3.2.2 Fuzzy DEMATEL

The DEMATEL method addresses the structural model and examines the cause-and-effect relationships among the criteria in complex systems (Yazdi et al., 2020). Prioritising the criteria and the resulting rankings is valuable for making long-term strategic decisions and developing improvement plans.

Therefore, fuzzy DEMATEL was applied to achieve the objective of rating the aspect's relationships based on their influence in optimising RCWR in New Zealand. Fuzziness was applied to reduce ambiguity and vagueness in experts' evaluations (Feng & Ma, 2020). Experts in the focus group were asked to evaluate the influence level of aspect I on aspect j by applying five different scales from 0 (No influence) to 4 (very high influence), as illustrated in Table 6.3.

Table 6.3: Fuzzy DEMATEL ranking scale

Definition	Fuzzy number			Scale
No Influence	0	0	0.25	0
Low Influence	0	0.25	0.5	1
Medium Influence	0.25	0.5	0.75	2
High Influence	0.5	0.75	1	3
Very High Influence	0.75	1	1	4

The procedure for using the DEMATEL technique is adapted from Si et al. (2018), Feng and Ma (2020), and Yazdi et al. (2020) which involved the following steps:

Step 1: The definition of the influence level in Table 6.3 was converted into the corresponding triangular fuzzy numbers. The triangular fuzzy number is a triplet (l, m, r) where l signifies a conservative value, closest to the actual value, m is the middle value, and r is the optimum value.

Step 2: The Complex System Cluster Fuzzy (CSCF) technique was applied to defuzzify the fuzzy numbers using equations (14) to (17) to normalise the triangular fuzzy numbers:

$$\mathrm{xl}_{\mathrm{ij}}^{\mathrm{k}} = \frac{\mathrm{l}_{\mathrm{ij}}^{\mathrm{k}} - \mathrm{minl}_{\mathrm{ij}}^{\mathrm{k}}}{\Delta_{min}^{max}} \quad (14)$$

$$\mathrm{x}m_{ij}^{k} = \frac{m_{ij}^{k} - minl_{ij}^{k}}{\Delta_{min}^{max}} \quad (15)$$

$$\mathrm{x}r_{ij}^{k} = \frac{r_{ij}^{k} - min\ _{ij}^{k}}{\Delta_{min}^{max}} \quad (16)$$

$$\Delta_{min}^{max} = \mathrm{maxr}_{\mathrm{ij}}^{\mathrm{k}} - minl_{ij}^{k} \quad (17)$$

Step 3: The *ls* and *rs* normalised values were computed using equations (18) and (19)

$$\mathrm{x}ls_{ij}^{k} = \frac{xm_{ij}^{k}}{\left(1 + xm_{ij}^{k} - xl_{ij}^{k}\right)} \quad (18)$$

$$\mathrm{x}rs_{ij}^{k} = \frac{xr_{ij}^{k}}{\left(1 + xr_{ij}^{k} - xm_{ij}^{k}\right)} \quad (19)$$

Step 4: The overall standard clear value was calculated by applying equation (20)

$$x_{ij}^{k} = \frac{xls_{ij}^{k} * \left(1 - xls_{ij}^{k}\right) + xrs_{ij}^{k} * xrs_{ij}^{k}}{\left(1 - xl_{ij}^{k} + xrs_{ij}^{k}\right)} \quad (20)$$

Step 5: For expert k, the clear value of the defuzzification was computed

$$z_{ij}^{k} = minl_{ij}^{k} + x_{ij}^{k} * \Delta_{min}^{max} \quad (21)$$

Step 6: A comprehensive evaluation was conducted to integrate the clear value and obtain the quantitative value of the direct influence degree of the index aspect *i* on *j*:

$$z_{ij} = \frac{Z_{ij}^{1} + Z_{ij}^{2} + \cdots + Z_{ij}^{P}}{p} \quad (22)$$

Step 7: The group direct influence matrix was formulated assuming an n number of aspects and l number of decision-makers using equation (23):

$$\mathrm{z_{ij}} = \frac{1}{\mathrm{l}} \sum_{\mathrm{k}=1}^{\mathrm{l}} \mathrm{z_{ij}^{k}} \quad \mathrm{i,j} = 1,2, \ldots, n \quad (23)$$

Step 8: The normalised direct influence matrix X was established using equations (24) and (25). The elements of matrix X must satisfy 0 ≤ xij <1, 0 ≤ $\sum nj$=1 xij ≤ 1, with at least one i such that $\sum nj$=1 zij ≤ s.

$$X = \frac{Z}{s} \quad (24)$$

$$s = max\left(\max_{1 \le i \le n} \sum_{j=1}^{n} z_{ij}, \max_{1 \le i \le n} \sum_{i=1}^{n} z_{ij}\right) \quad (25)$$

Step 9: Using the normalised direct-influence matrix X, the total influence matrix T = $[t_{ij}]n\times n$ was found by computing equation (26)

$$T = X + X^2 + X^3 + \cdots + X^h = X(I - X)^{-1} \qquad h \to \infty \quad (26)$$

Step 10: The influential relation map (IRM) is generated at this step by computing the sum of the rows *R* and the sum of the columns *C* in the total-influence matrix T using equations (27) and (28)

$$R = [r_i]_{n\times 1} = \left[\sum_{j=1}^{n} t_{ij}\right]_{n\times 1} \quad (27)$$

$$C = \left[c_j\right]_{1\times n} = \left[\sum_{i=1}^{n} t_{ij}\right]_{1\times n}^{T} \quad (28)$$

where r_i is the i^{th} row sum, and c_j is the j^{th} column sum in the matrix T. Both sums represent the total direct and indirect influence of the aspects both given and received. For instance, assume j = i and i, j ∈ {1, 2, . . ., n}; the "Prominence" denotes the horizontal axis vector (R + C), signifying the cumulative impact of a factor in terms of both contribution and reception. In other words, $R + C$ represents the expanded influence of the factor role within the system. Similarly, "Relation" denotes the vertical axis vector ($R-C$). The equation ($rj - cj$) represents the directional vector from the centre (C) to the location (R), indicating the overall influence of the factor on the system. If ($rj - cj$) is positive, the factor Fj has a negative influence on other factors and can be classified as a cause. Conversely, if ($rj - cj$) is negative, the factor Fj is influenced by other factors and belongs to the effect group. Mapping the dataset of (R+C, $R-C$) provides valuable insights for decision-making.

After identifying the causes and effects of the aspect, the specific relationships between the causes and their corresponding effects remain unclear. According to Nair and Manohar (2024), establishing a threshold clarifies the significant cause-and-effect relationships. Therefore, the threshold was determined by computing the Mean (**µ\muµ**) of the total relation matrix Tusing equation (29):

$$\mu = \frac{1}{n^2} \sum_{\{i=1\}}^{n} \sum_{\{j=1\}}^{n} T_{ij} \quad (29)$$

6.4 Results and Analysis

6.4.1 Focus group A – Red

Based on the results from the weighting and scoring process (see Figure 6.2), the red focus group ranking for the factors was as follows: EC>Gov>PP>OP>OG>IT>ENV>SB. Figure 6.2 highlights the significant influence of the EC, Gov, IT, and OG aspects representing the causes (drivers), which have high relation and prominence values, indicating a direct, substantial influence on improving RCWR. Conversely, the SB, OP, ENV, and PP aspects have effect relationships reflecting the outcome of improving the cause factors and do not directly enhance RCWR. Table 6.4 illustrates the cause-and-effect relationships between the factors in RCWR. The Gov and EC factors exert the most significant influence on the other variables, specifically SB, OP, ENV, and PP. In contrast, the IT factors primarily affect OP, ENV, and PP, while the OG factors predominantly influence OP and PP.

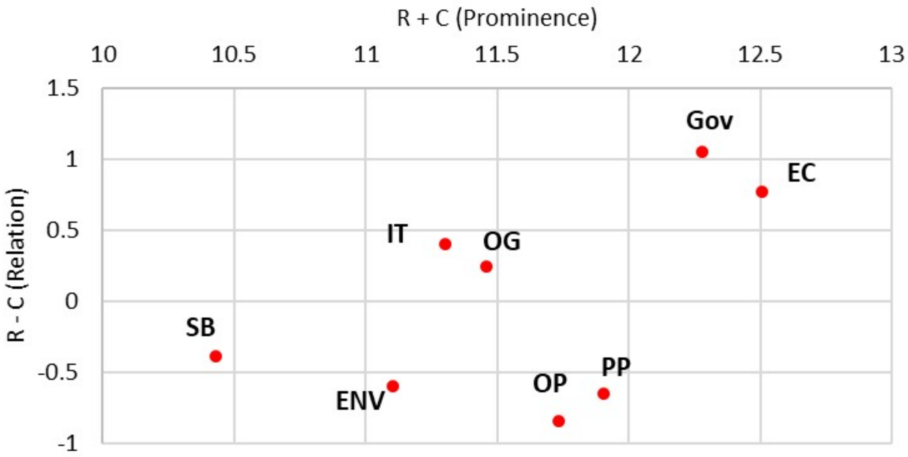

Figure 6.2: The IRM for cause-and-effect aspect relationships- Group A

Table 6.4: Total relation matrix reduced after threshold-Group A

Effect / Cause	OP	ENV	PP	SB
EC	0.910669	0.856266	0.909755	0.800839
IT	0.791918	0.772472	0.81722	
OG	0.818077		0.818935	
Gov	0.913543	0.860622	0.912574	0.80413

The Ec factors were prioritised as the most significant driving the RCWR system, particularly Ec3 and Ec4, both receiving a score of 100% (see Table 6.5). This indicates that strategies addressing the rising construction costs, and the limited profitability of waste reduction practices can lead to improved RCWR outcomes. This was followed by the governance aspect, which suggests the red group's support for penalties for non-compliance, higher waste levies, mandatory waste plans, and government support in workforce training, research, and education across the industry to drive progress in RCWR. The priority factors for the governance aspect are significant findings, indicating the urgency and necessity of such measures in New Zealand. Additionally, the red group's third priority aspect is the PP factors, highlighting the linear business operational model as challenging to progress in RCWR. This is followed by the OP aspect prioritising the customisation requirements in design or bespoke design and the lack of infrastructure for waste sorting and diversion practices, suggesting the need for targeted design strategies and infrastructure to drive improvement.

Moreover, the influence ranks of IT and OG aspects are the fifth and sixth in priority aspects, respectively. The results suggest that transportation challenges currently restrain off-site manufacturing and stress the need for more internally tailored training programs within residential construction companies. Although the least priorities were given to the ENV and SB aspects, the top-ranked factors highlighted a significant influence on the responsibility of manufacturers and suppliers for the product's end-of-life and the need for the shift in the perception of waste as an opportunity rather than a problem.

Table 6.5: Priority ranking for factors- Group A

Aspect	Factor code	Scoring result (%)	Priority factor
EC	Ec3	100%	The increased cost of building hinders adopting waste reduction practices.
	Ec4	100%	Limited profitability of waste restricts competition and market development to progress in waste reduction.
Gov	Gov1	73%	Regulatory changes, such as changes to building codes, are necessary for waste reduction.
	Gov3	73%	Penalties for non-compliance as a driver towards waste reduction.
	Gov4	73%	Waste plans as a mandatory requirement on the project level.
	Gov5	73%	A higher waste levy will force people to consider alternative waste disposal methods.
	Gov9	73%	A waste reduction holistic approach involving government support, workforce training, incentivisation, research, and education.
PP	PP9	100%	Businesses operating under a linear model find it challenging to progress in waste reduction.
OP	OP6	100%	Custom-designed homes or bespoke design
	OP14	100%	The lack of proper infrastructure negatively affects waste sorting and diversion practices.
IT	IT6	100%	Transportation challenges limit adopting off-site manufacturing.
OG	OG8	100%	The limited availability of internal training programs for waste reduction in residential construction companies.
ENV	ENV4	100%	Manufacturers and suppliers should take responsibility for the end-of-life of their products.
	ENV5	100%	The responsibility for waste reduction lies with the entire supply chain
	ENV6	100%	Collaboration with manufacturers and suppliers to propose alternative materials with better end-of-life options
SB	SB2	100%	The perception of waste as a problem rather than an opportunity.

6.4.2 Focus group B – Green

The scores for the green group had the highest influence on the factors related to the OP aspect in the following sequence: OP>PP>OG>ENV>EC>Gov>SB>IT (see Figure 6.3). The top-ranked factor in OP suggests addressing the alignment of design specifications with the available dimensional materials in the market. Table 6.6 demonstrates the overall significant relationship among the factors, showing that OP factors, along with ENV and EC, are influenced by the causal factors IT, PP, OG, and Gov. While the SB factors are influenced by PP, OG, and Gov.

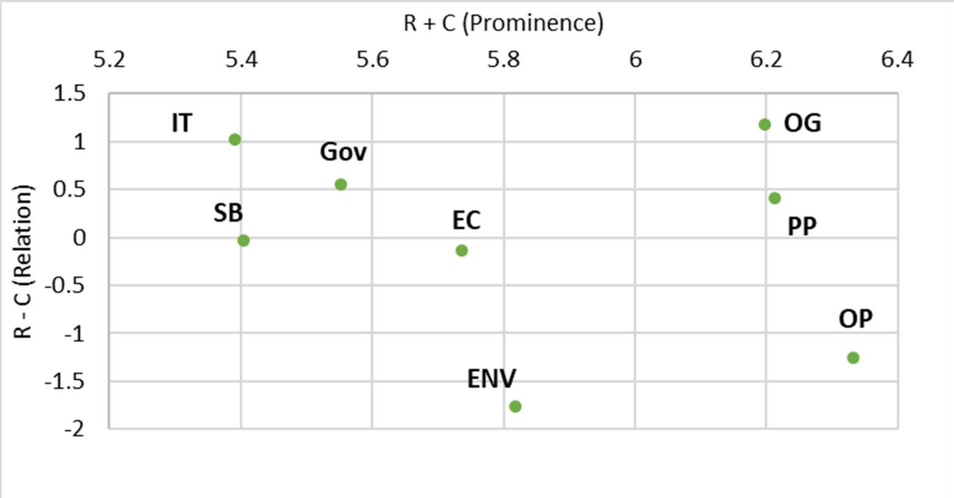

Figure 6.3: The IRM for cause-and-effect aspect relationships– Group B

Table 6.6: Total relation matrix reduced after threshold-Group B

Effect / Cause	OP	ENV	EC	SB
IT	0.526278	0.526278	0.441277	
PP	0.539284	0.539284	0.445961	0.423989
OG	0.586102	0.586102	0.483236	0.456675
Gov	0.506853	0.506853	0.392409	0.372817

The results of priority ranking (see Table 6.7) suggest that resource allocation and strategic planning should focus on residential construction companies challenged by the lack of technical expertise, offsite manufacturing limitations, and access to best practices in RCWR, particularly small-scale ones. The green group agrees with the red group on the most priority factors in the SB, ENV, PP and IT aspects. In addition, the green group nominated waste plans as a mandatory requirement on the project level to be given the highest priority in government strategic planning for RCWR and standardisation. Also, the green group result indicates that while implementing regulations is essential for maintaining compliance, their effectiveness can be limited if not adequately executed during implementation.

Table 6.7: Priority ranking for factors- Group B

Aspect	Factor code	Scoring result (%)	Priority Factor
OP	OP4	100%	Design specifications' alignment with the available dimensional materials in the market.
PP	PP2	100%	Limited accessibility of best practices, especially for smaller-scale builders.
	PP9	100%	Businesses operating under a linear model find it challenging to progress in waste reduction.
OG	OG6	100%	Lack of technical expertise for small residential construction companies.

ENV	ENV1	100%	Public awareness about the environmental impact of residential construction practices.
	ENV2	100%	Highlighting the impact of waste on New Zealand's natural beauty and finite resources inspires the behaviour towards waste reduction.
	ENV4	100%	Manufacturers and suppliers should take responsibility for the end-of-life of their products.
	ENV5	100%	The responsibility for waste reduction lies with the entire supply chain
	ENV6	100%	Collaboration with manufacturers and suppliers to propose alternative materials with better end-of-life options
EC	EC1	100%	The cost of waste reduction often outweighs the benefit.
	EC4	100%	Limited profitability of waste restricts competition and market development to progress in waste reduction.
Gov	Gov4	66%	Waste plans as a mandatory requirement on the project level.
	Gov5	66%	A higher waste levy will force people to consider alternative waste disposal methods.
	Gov6	66%	Regulations are necessary but can be diluted during implementation.
	Gov9	66%	A waste reduction holistic approach involving government support, workforce training, incentivisation, research, and education.
	Gov10	66%	Lack of standardisation contributes significantly to construction waste, particularly off-cut waste.
SB	SB2	100%	The perception of waste as a problem rather than an opportunity.
IT	IT6	100%	Transportation challenges limit adopting off-site manufacturing.

6.4.3 Focus group C– Blue

The Blue group ranked the influence of factors as follows: ENV>Gov>SB>OG>EC>IT>OP>PP (see Figure 6.4). The relation scores in Table 6.8 support the significance of these aspects, indicating the driver's role of the EC, Gov, IT, and SB factors and the influential effect of OP, ENV, PP, and OG factors in RCWR. The blue group scoring result for the driving role of IT and Gov factors agreed with the red and green groups.

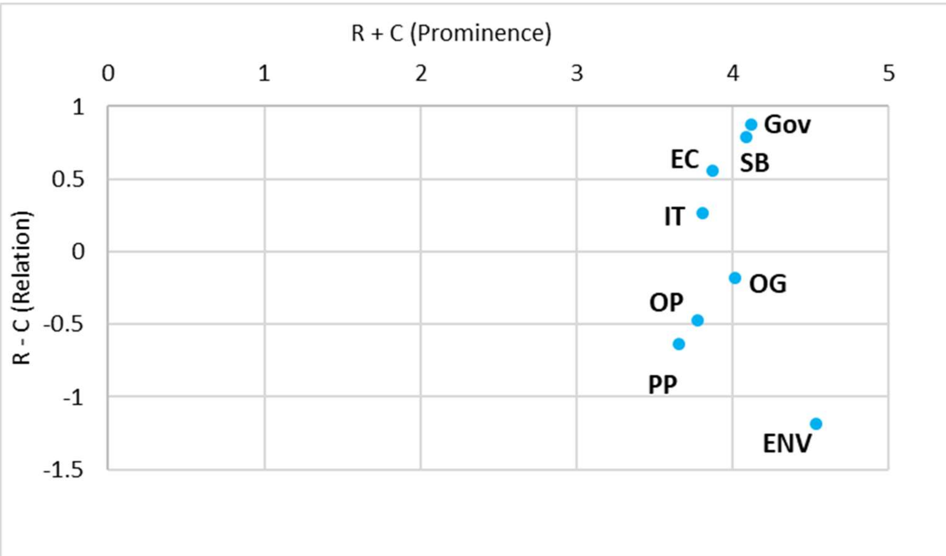

Figure 6.4: The IRM for cause-and-effect aspect relationships– Group C

Table 6.8: Total relation matrix reduced after threshold-Group C

Cause \ Effect	OP	ENV	PP	OG
EC	0.314706	0.409399	0.270665	0.290294
IT	0.250541	0.357775	0.277248	0.296336
SB	0.311668	0.436853	0.339466	0.332877
Gov	0.341312	0.444799	0.343784	0.338357

The priority scoring results, as shown in Table 6.9, indicate that the primary focus of the government's strategic direction in RCWR should be addressing challenges related to building code compliance and the introduction of sustainable and innovative building materials. The blue group agreed with the green and red groups on the top-ranked factors in PP, ENV, SB, and EC, suggesting similar strategic direction and shared interests. In addition, the blue group nominated the limited adoption of offsite manufacturing in small-scale projects and the related constraints of its implementation, such as project size, customisation requirements, training needs, and cost, as the priority for strategic direction in IT.

Table 6.9: Priority ranking for factors- Group C

Aspect	Factor code	Scoring result (%)	Priority factor
GOV	Gov2	100%	Compliance with building code requirements is a challenge to getting more choices in sustainable materials.
SB	SB2	100%	The perception of waste as a problem rather than an opportunity.
ENV	ENV2	100%	Highlighting the impact of waste on New Zealand's natural beauty and finite resources to inspire behaviour change.
	ENV4	100%	Manufacturers and suppliers should take responsibility for the end-of-life of their products.
	ENV5	100%	The responsibility for waste reduction lies with the entire supply chain
	ENV6	100%	Collaboration with manufacturers and suppliers to propose alternative materials with better end-of-life options
OG	OG6	100%	Lack of technical expertise for small residential construction companies.
EC	EC1	100%	The cost of waste reduction often outweighs the benefit.
	EC3	100%	The increased cost of building hinders adopting waste reduction practices.
	EC4	100%	Limited profitability of waste restricts competition and market development to progress in waste reduction.
IT	IT5	100%	Off-site manufacturing is not widely implemented in smaller-scale projects.
	IT7	100%	Constraints such as project size, customisation requirements, training needs, and cost currently limit the widespread adoption of off-site manufacturing.
	IT11	100%	Building code compliance limits introducing innovative construction materials.

OP	OP12	100%	Space limitations make accommodating separate bins for different materials difficult.
PP	PP9	100%	Businesses operating under a linear model find it challenging to progress in waste reduction.

6.4.4 Balanced interests of the RCWR decision-makers

Figure 6.5 illustrates the balanced influence ranking results for the factors as follows: ENV>OP>Gov>OG>EC>PP>IT>SB. The cause factors are EC, IT, SB, OG, and Gov, while the effect factors are OP, PP, and ENV (see Table 6.10). The ranking of the ENV and OP factors demonstrates high importance but low correlation, signifying their critical priority but limited influence on other factors (refer to Figure 6.5, Table 6.10). Therefore, this result suggests that environmental and operational factors are crucial for the stakeholders but are strategically driven by the cause factors without direct intervention.

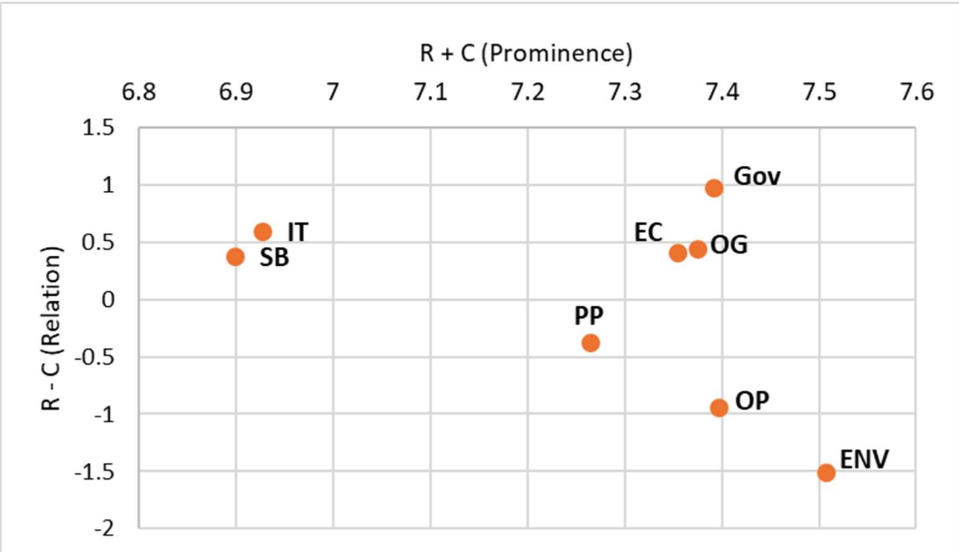

Figure 6.5: The balanced interests IRM for cause-and-effect relationships

Table 6.10: Total relation matrix reduced after threshold- Balanced interests

Effect / Cause	OP	ENV	PP
EC	0.574324	0.619527	0.509268
IT	0.534212	0.593799	0.514929
SB	0.519754	0.580074	0.484087
OG	0.577148	0.594258	0.531106
Gov	0.60958	0.657535	0.559383

According to Table 6.11, ENV factors, particularly manufacturers' and suppliers' accountability for the end-of-life of their products and the responsibility across the supply chain for RCWR, are of great significance.

Moreover, the results revealed the necessity for New Zealand to invest in partnerships with manufacturers and suppliers to propose alternative materials that offer better end-of-life options. Regarding strategic priority in RCWR, New Zealand can benefit from prioritising small residential construction companies for technical advice and investigating challenges related to transitioning to a circular economy business model. Additionally, incentivising RCWR and developing a market strategy to unlock waste profitability and encourage investment opportunities can help stabilise long-term RCWR strategies and serve as foundational enablers for other factors.

The priority ranking places Gov factors third, underscoring the importance of mandatory waste plan requirements at the project level. The balanced interests IRM results (see Figure 6.5) exhibit high prominence and a strong correlation for Gov on the effect factors, indicating a pivotal role in driving ripple changes to RCWR. Targeting Gov factors strategically can yield substantial improvements and wield significant influence over other RCWR factors. The IT and SB factors were found to have the lowest priority, with slight prominence and a high degree of correlation in the scoring results (refer to Figure 6.5). The findings indicate that addressing these factors strategically could have a significant impact on the effect factors, ultimately leading to a positive change in RCWR. However, these factors are not currently prioritised. This suggests that there is a risk of these factors being overlooked, which could cause New Zealand to miss opportunities for optimisation.

Lastly, the OP factors are assigned a second ranking with high prominence but low relation. The results indicate that the real influence of OP on other RCWR factors is limited but receiving greater attention and is highly visible, which could be driven by other external factors such as regulation requirements. Therefore, New Zealand can benefit from directing resource allocation and strategic efforts towards priority areas (see Table 6.11), such as limitations in design specifications and constraints of onsite sorting, while keeping the influence on the OP factors monitored.

Table 6.11: Priority ranking for factors- Balanced interests

Aspect	Factor code	Scoring result (%)	Priority factor
ENV	ENV4	100%	Manufacturers and suppliers should take responsibility for the end-of-life of their products.
	ENV5	100%	The responsibility for waste reduction lies with the entire supply chain
	ENV6	100%	Collaboration with manufacturers and suppliers to propose alternative materials with better end-of-life options
OG	OG6	100%	Smaller residential construction companies often lack technical expertise.
Gov	Gov4	100%	Waste plans as a mandatory requirement on the project level.

OP	OP4	100%	The design specifications may not align with the available dimensional materials in the market.
	OP12	99%	Space limitations make accommodating separate bins for different materials difficult.
PP	PP9	100%	Businesses operating under a linear model find it challenging to progress in waste reduction.
Ec	Ec4	100%	Limited profitability of waste restricts competition and market development to progress in waste reduction.
SB	SB2	100%	The perception of waste as a problem rather than an opportunity influences the attitude towards waste reduction.
IT	IT6	95%	Transportation challenges could limit adopting off-site manufacturing.

6.5 Strategy (ST) Development

As New Zealand continues to look forward to optimising performance in RCWR, it is essential to create the necessary policies and strategies. Therefore, the group discussion on strategy development focused on translating the insights from the weighting and scoring results into actionable strategies to address the opportunities within RCWR in New Zealand. Figure 6.6 summarises the key strategies proposed in the three groups, which are discussed in detail in this section.

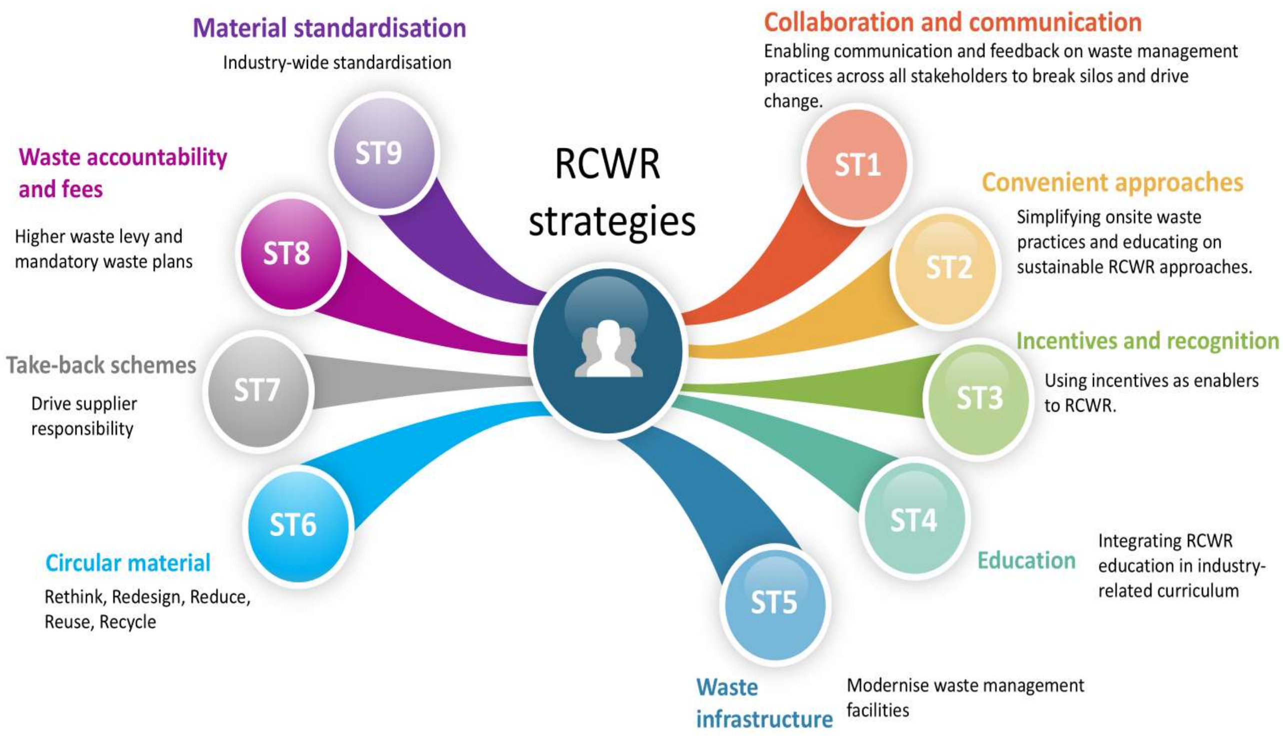

Figure 6.6: Critical strategies for RCWR optimisation in New Zealand

6.5.1 ST1 Collaboration and communication

The blue group described the residential construction system as a production line having multiple "pockets" with front, middle, and end processes. The system front is design, the middle is construction, and the end of the system is the delivery. The discussion recommended enabling communication and feedback on waste management practices between the front, middle and end of the system to break silos and bridge the gap across all stakeholders. The group emphasised that collaborative work influences change, as follows:

"We still do not have that communication in between, and we will never know if that has been done or applied or if the results were effective or not."

6.5.2 ST2 Convenient approaches

The blue group discussion pointed out simplifying onsite waste practices, educating the site team on the importance of performing these practices, and guiding them through the process. The group highlighted that the onsite practices can only be optimised if designers consider materials that have the potential for recycling or reusing.

"We have got to shift the mentality on-site by having convenient, practical processes as an alternative. The alternative has got to be something they can easily do and see its worth as if they know the product will have another use and not end up in the landfill anyway."

However, the green group highlighted the uncertainty surrounding the reprocessing of specified materials for designers. While it is known that metal can be melted down and turned into new metal, the reprocessing method for other highly processed products remains unclear.

6.5.3 ST3 Incentives and recognition

The blue group recommended using incentives as enablers to RCWR. They suggested creating a category for high compliance regarding recognition for best performance or a point-based reward system based on the amount of waste diverted, with rewards in the form of money. The red group supported an increase in waste levy and suggested having an energy and environment rating different from Homestar, which is on counts. Nevertheless, a fundamental system on each home's limb to track and benchmark the performance in meeting health, safety, and environment targets. In this regard, the red group made two recommendations. The first recommendation is as follows:

"To increase the waste levies for the construction industry, we would require a measured waste permit by bill. For each bill, you would have X per cent by health, safety, and environment, especially for a big company."

The second recommendation is to offer positive incentives for waste reduction, such as adding a credit to the billing; if targets are met, X percent of the fees are reduced.

"Waste management as an opportunity to gain profit would trigger some businesses to find an opportunity."

Moreover, the blue group highlighted two points to consider in material waste. The First is the type of materials, and the second is the packaging waste, as there is a massive overuse of packaging material. A proposed strategy involves contacting suppliers and arranging material delivery without wrapping packages. The green group recommended government incentives for the supplier to enable take-back schemes. Furthermore, the blue group explained that many considerations are into materials because materials raise the house value, not only monetary but because of considering every aspect of design out waste. However, the ultimate measure of value is the house sale value. Therefore, the group suggested a mainstream adaptation to design out waste and choosing materials with waste diversion potential as follows:

"We need it to be adopted by the masses to have an effect. It cannot just be a marginal thing, a niche thing. It is got to be a mainstream adaptation, or it just will not have the effect that we need it to have."

6.5.4 ST4 Education

The blue and red groups discussed educating stakeholders, including design professionals, tradespeople, and suppliers. The blue group suggested integrating waste management into the training and education of designers and engineers, involving active waste streams to educate them about waste disposal and materials. The experts also recommended incorporating waste management education into trade apprenticeships, as different aspects of the trades produce specific types of waste. The red group pointed out that educational tools must be provided with mandatory waste management plans.

"If waste management plans become mandatory, we want to ensure that educational tools are provided in the program."

6.5.5 ST5 Waste infrastructure

The blue group discussed the importance of improving waste management facilities (e.g., sorting and recycling centres) to drive innovation and ensure that information on platforms for searching recycling destinations is regularly updated with new opportunities. Additionally, the green group proposed the establishment of a redistribution centre where repurposed materials are available to purchase.

"It would be great if there were a redistribution centre where people could go and buy repurposed materials."

6.5.6 ST6 Circular materials

The blue group emphasised that the future of design involves using circular materials, which will allow houses to be easily deconstructed, and the materials reused. Companies should be incentivised to demolish structures without cost and resell or recycle the materials. The group highlighted the need to solve problematic materials that escape into the environment and implement the five Rs principles (rethink, redesign, reduce, reuse, recycle). Using circular materials is essential, but cost concerns may hinder widespread adoption.

"One of the things in the future with design is circular materials so that if the house or the building has to be pulled down, you have got a destination. But, unless the customer or client is pushing that, it is really hard because we are cost-driven."

6.5.7 ST7 Take-back schemes

The green and red groups recommended structuring a take-back scheme. The green group explained that when a product is purchased from a manufacturer, and excess waste is generated, the manufacturer should collect and reprocess the waste to recycle it. The government should incentivise this process with tax deductions for the supplier or manufacturer. The red group emphasised that:

"Big issue in construction we see is that we incentivise the use of materials, and everyone puts up with, if we suggest taking your rubbish back, that might change things a little bit."

6.5.8 ST8 Waste accountability and fees

The blue group highlighted that everybody, especially the public, is responsible for waste. The red group suggested enforcing a mandatory waste management plan with specific targets and raising the waste levy, while the green group recommended implementing a waste management policy to promote RCWR during the design as follows:

"Thoughtful design from the construction stage, the recommendation would be a waste management policy. If it is site-specific, it can be part of the consent."

6.5.9 ST9 Material standardisation

The green team proposed standardising materials to reduce waste and streamline the design process by limiting material options. During the discussion, it was suggested that standardisation could benefit suppliers by providing consistent material parts and promoting sustainable practices such as reusing and recycling rather than solely focusing on reducing construction waste on site. An emphasis by the green group is as follows:

"From a supplier point of view, standard revision can be a big thing. As in a more visible set of an industry-wide published set, these are our standard industry sizes. It gives a bit of flexibility when I go to suppliers and do not do site measurements; I do not need any of it. It also simplifies the design process and ensures the wastage is clean."

During the green group discussion, it was proposed that increasing the number of suppliers for specific materials would allow competition to provide a greater variety of product lengths, thus reducing wastage. Having more options could address the issue of design specifications not matching the dimensions and materials currently available in the market.

"If we are using just four or five types of window sizes, imagine if I am doing similar sorts of houses with similar window sizes for quantity estimation. So, it is about standardisation but also choice."

6.6 Discussions and Practical Implications

Optimising RCWR requires a collaborative and comprehensive approach to formulating strategies and policies that facilitate groundbreaking change across the residential sector. The proposed findings and strategies aim to benefit New Zealand in performance improvement by setting forth the priority factors of RCWR in decision-making while considering their influential relation. The results suggest a three-dimensional responsibility to RCWR, including (i) industry responsibility, (ii) supplier responsibility, and (iii) government responsibility. The industry's responsibility as a consumer drives the supplier's responsibility by increasing the market demand for more materials with RCWR potential. However, to drive consumer demand, a comprehensive educational approach that involves practical training and curriculum integration for RCWR should be implemented.

Regarding the government's responsibility, it is necessary for New Zealand to incentivise RCWR, review the building code, and impose higher penalties on CW compliance. Mahpour and Mortaheb (2018) revealed that incentives are more effective than penalties in CW reduction, driving positive behaviour change, which promotes ethics and contributes to SDGs. An incentive-based CW policy also leads to a shift in the perception of waste by making it profitable to encourage competition and market development. This strategic approach establishes shared responsibility for material recovery across the supply chain and unlocks a circular economy. A. Zhang et al. (2021) suggested developing circularity metrics for products and supply chains and highlighted the need for collaboration to develop appropriate metrics, addressing the challenges of complex global supply chains and the wide range of materials.

In addition, the results highlight the impact of workforce training and technical proficiency on RCWR performance. Despite the significant contribution of the New Zealand construction sector to the economy, the turnover rate can reach up to 20%, which may pose challenges for workforce planning and lead to increased costs for training (Ayodele, Chang-Richards, & González, 2022). Thus, the residential sector must adapt to the workforce dynamics and invest in developing robust retention strategies and innovative construction methods, which is crucial to meeting the demand challenges and opportunities in RCWR. Additionally, the Ministry of Business Innovation & Employment-MBIE (2023a) reported that small and medium construction businesses in New Zealand are more likely to experience a decline in growth than large businesses, indicating a need for support in resource allocation and technical advice for RCWR.

6.7 Conclusions and Future Research

The aim of this research was to develop and validate a decision-making framework for RCWR in New Zealand. The objectives comprised identifying the criteria for factors influencing RCWR and assessing their relative importance by balancing the interests of various decision-makers involved. This was achieved using the fuzzy TOPSIS and fuzzy DEMATEL techniques. Data were collected through a focus group workshop, providing a comprehensive understanding of RCWR strategy and policy priorities.

From the results, ENV factors are crucial but have limited influence from other factors, while GOV factors are third in priority, highlighting the importance of mandatory waste plan requirements. IT and SB factors have the lowest priority and risk of being overlooked, potentially leading to missed optimisation opportunities in New Zealand. The OP factors have a middle priority with limited influence on other factors, requiring monitoring while resources are directed towards more significant areas. Additionally, OG, Ec, and PP factors play a balancing role in the system, likely influencing and contributing meaningfully to other factors.

This study's strategic directions (i.e., ST1 to ST9) underscore the significance of a collaborative and holistic approach to driving positive change in RCWR. The recommendations for RCWR encompass education, circular materials, take-back schemes, convenient approaches, incentives and recognition, waste infrastructure, as well as waste accountability and fees. The limitations of this study are primarily associated with the generalisability of the results, and the narrower focus on RCWR without fully considering supply chain factors, circular economy principles, and elements of the regulatory framework. Although the focus group enhanced the validity and practicality of the developed framework, results cannot be generalised to different contexts, but can be transferred to other locations. Participants in the focus group were purposefully selected to represent a diverse range of perspectives and experiences, so the results are specifically relevant to New Zealand. A larger sample size in different locations could provide insights into a broader range of subjective areas and outcomes.

Moreover, future research could benefit from developing case studies to evaluate and compare various scenarios of supply chain design or policy frameworks. Further studies could evaluate the effectiveness of incentives versus penalties in RCWR. There is also potential for research investigating the impact of developing metrics for product and supply chain circularity on RCWR, as well as modelling the influence of workforce dynamics on RCWR performance.

Chapter 7 Discussion and Conclusion

7.1 Overview

This chapter presents the findings of the conducted research, beginning with an interpretation of the research aim and objectives. Subsequently, an outline is provided of how the research questions were approached and the objectives achieved. Additionally, a clarification of the research's contribution to the existing body of knowledge is provided, followed by addressing the research limitations. The chapter concludes by providing recommendations for future studies.

7.2 Fulfilment of Research Aim and Objectives

The primary aim of this study was to develop a framework to optimise the decision-making process in developing RCWR strategies within the New Zealand context. Four objectives were established to achieve this research aim. These objectives are summarised in the following sub-sections.

7.2.1 Research Objective 1: To articulate the fundamentals of RCWR

The first objective of the research was to articulate the fundamental concepts of RCWR from existing literature. Accordingly, two research questions (RQs) were put forward:

- ***RQ1****: What are the concepts of RCWR?*
- ***RQ2****: Who are the key stakeholders of RCWR?*

To address ***RQ1***, a systematic literature review covered 87 articles and identified five key themes: (i) waste generation and management performance, (ii) prefabrication and LCA concepts in RCWR, (iii) design concepts in RCWR, (iv) circular economy and (v) decision-making concepts in RCWR. The results emphasised the significant contribution of sustainable construction practices such as prefabrication, 3DP, and BIM in achieving RCWR. The results also revealed four categories of potential benefits to RCWR implementation, including economic, environmental, and social benefits and accelerating the achievement of sustainable development and circular economy. Moreover, the results outlined the barriers to achieving RCWR, including management, economic, cultural, communication, legislative, and technological barriers. The results yielded the necessity of a standardised measurement and reporting system for quantifying residential CW, as well as for improved RCWR planning in New Zealand.

For ***RQ2***, a systematic literature review was conducted, which led to the development of a conceptual model of stakeholders' interactions and contributions to RCWR. The identified stakeholder groups encompassed eight categories, with the highest recognition for the designer role, at 55%, followed by the contractor (44%), regulator (40%), supplier (36%), project manager (25%), subcontractor (21%), client (20), and RCWR services provider (17%).

The key stakeholders are the ones involved in the design and planning of the residential construction process, including the client, designer, contractor and project manager. Another critical role was perceived for the regulator in RCWR. The results emphasised the importance of client investment in RCWR strategies, the regulator's responsibility in promoting best practices, the need for regional-level benchmarking, and the collaborative efforts of contractors, designers, and project managers in implementing RCWR practices. The findings also highlight (i) the importance of data in designing a WMP, (ii) the effective communication with suppliers, and (iii) the role of subcontractors in waste sorting practices. Lastly, the findings stress the significance of role clarity for effective RCWR compliance within the project's time and budget.

The review echoed the need for the New Zealand construction industry to embrace a broader range of strategies to optimise the benefits of RCWR. Recommendations were made for short-term and long-term planning. Short-term recommendations included comprehensive project planning, training programs, and improved procurement practices to enhance RCWR. Additionally, the findings highlighted the importance of educational initiatives to promote attitudinal and behavioural change among stakeholders. Furthermore, the review recommended collaboration between the construction industry and the government to drive innovation and improve business performance.

Since CW reduction is the optimal strategy in the principles of CW management, it has the least negative environmental impact. Thus, the RCWR strategy should be prioritised at the project level in the WMP and the national level with incentives. Effective CW reduction involves preventing waste creation and facilitating ways to reuse and recycle materials (Kabirifar et al., 2020). Effective construction waste reduction involves preventing waste generation and promoting the reuse and recycling of materials. Additionally, CW reduction must begin at the design and planning stages, before waste is created on the construction site (Osmani & Villoria-Sáez, 2019). Success in implementing the CW strategy relies on effective communication and collaboration among the stakeholders involved in the construction project.

Implementing long-term recommendations for optimising RCWR and ensuring a sustainable and resilient residential built environment emphasises the need for a business model that considers RCWR in residential materials and components supply, the implementation of a national RCWR strategy, and the involvement of designers, regulators, and researchers in promoting RCWR within their projects. The practical implication of the review also highlights the gaps in the current waste strategy in New Zealand, such as the need for defined, measurable targets for RCWR and clear guidelines for reducing the use of materials with high waste profiles. Additionally, introducing innovative construction methods, enhancing design for waste reduction, and expanding the accessibility of waste management infrastructure to facilitate recycling and waste sorting at construction sites were recommended strategies.

7.2.2 Research Objective 2: To investigate the factors Influencing RCWR in New Zealand

The second objective of the research was to investigate the factors influencing RCWR in New Zealand. Accordingly, one research question was put forward as follows:

- ***RQ3****: What factors influence RCWR in New Zealand?*

To address ***RQ3***, semi-structured interviews were conducted with key New Zealand stakeholders, as identified and characterised under the first research objective. Three questions were asked during the interviews; *(i) What are the constraints in implementing RCWR practices in New Zealand? (ii) How can RCWR practices be prioritised? (iii) How can RCWR be effectively promoted in New Zealand?* (see Appendix B for interview protocol). The interview results revealed eight categories of factors with 25 sub-factors influencing RCWR in New Zealand.

Design optimisation in the operational category and awareness and education in the behavioural category received the highest recognition from all the interviewees. Insights from the design optimisation highlighted that design and planning are crucial for RCWR, and collaboration between designers and builders is essential, emphasising the findings in Chapters 2 and 3. Specific insights for New Zealand indicated that architectural practices currently have a limited focus on environmentally preferable materials and RCWR. Additionally, the diversity in residential design in New Zealand is a common cause of CW due to custom requirements and non-standard dimensions.

Moreover, awareness and education emphasised the importance of creating awareness about the benefits of RCWR and the available resources and educating stakeholders about best practices for RCWR. This finding highlights the need for practical education and integrating sustainability into every role within RCWR, changing the perception of waste and incentivising RCWR. The findings suggest that streamlining the education process of RCWR will drive demand for sustainable materials and practices.

The second highest recognition was to the regulation and policy in the governance category and logistics and infrastructure in the operational category, receiving 87% from the interviewees. The results emphasised the need for education and awareness before regulation and suggested conducting a cost-benefit analysis before implementing regulations. This finding also highlights the inadequacy of the building code to stimulate the market of sustainable building materials without increasing costs. Regarding the influence of logistics and infrastructure, results highlight challenges such as inadequate infrastructure, transportation difficulties, and the need for secure storage for waste materials to facilitate reusing and recycling. A significant highlight for New Zealand is the regional variations in infrastructure capacity, with the Auckland region being the most accessible to waste infrastructure due to the large scale of residential projects. Moreover, the results revealed the importance of proactive planning and strategies like stockpiling and reverse logistics to address these challenges.

The findings in Chapter 4 offered valuable insights into the priority areas for strategy development in RCWR, including promoting education and awareness to drive behavioural change. This involves integrating education across all stages of the construction process and offering it to all stakeholders involved in RCWR. Tailored education and training programs are encouraged at an industry level and should be incorporated into university curricula and apprenticeship programs. Additionally, implementing a comprehensive view of the RCWR system requires credible data and addressing the limitations of building codes. Data-driven decision-making, rewarding performance, and incentivising successful waste reduction are highlighted as powerful drivers for effective RCWR.

7.2.3 Research Objective 3: To evaluate the importance of factors influencing RCWR in New Zealand

The third objective of the research was to evaluate the importance of factors influencing RCWR in New Zealand. Accordingly, one research question was put forward as follows:

- ***RQ4**: How important are the factors influencing RCWR?*

To address ***RQ4**,* a questionnaire survey (see Appendix B for the survey) of 146 indicators was developed and distributed among experts with relevant experience in RCWR in New Zealand. A total of 62 responses were collected and validated, and a model with 10 hypotheses was developed. The PLS-SEM was then performed to assess the measurement and structural models of the hypothesised model. Results of the PLS-SEM confirmed and accepted all hypotheses and retained 98 of the factors.

The results supported the acceptance of all proposed hypotheses and suggested a substantial influence for the OP, SB, ENV and Gov. An emphasis on the substantial influence of organisational practices, stakeholder collaboration, environmental awareness, and government interventions was highlighted. Additionally, government interventions should focus on the building code, stakeholder collaboration, financial incentives, and waste infrastructure. The results underscore that local companies should prioritise planning, access to waste infrastructure information, and supply chain accountability. Innovation, regulations, and management support are critical in improving RCWR performance. The insights would aid in optimising performance, developing strategies, and formulating policies in the field of RCWR. Additionally, the results stressed the significance of early planning and design, as well as the role of government regulations, as discussed in Chapter 3.

7.2.4 Research Objective 4: To develop and validate the RCWR framework

The final objective of the study involved the validation of the developed decision-making framework by applying the MCDM techniques of fuzzy DEMATEL and fuzzy TOPSIS.

The final objective of the research was to develop and validate the RCWR framework. Accordingly, one research question was put forward as follows:

- ***RQ5****: How can a decision-making framework for RCWR in New Zealand be developed and validated?*

To address ***RQ5,*** a focus group workshop was conducted with experts in RCWR. The focus group workshop was titled "A Decision-making Framework for Residential Construction Waste Reduction (RCWR) in New Zealand" and involved ten decision-makers, organised into three groups: Group A (red) with 3 experts, Group B (green) with 3 experts, and Group C (blue) with 4 experts. The findings from achieving **RO3** were used to develop the MCDM framework tailored for optimising RCWR in New Zealand. The process involved three fundamental steps, which are: defining objectives and parameters, analysing data from decision-makers, and interpreting the results. The framework’s aim was to balance stakeholders' interests and assess the influence of the different categorised factors on RCWR optimisation by ranking and weighting the aspects and factors using the combined techniques of fuzzy DEMATEL and fuzzy TOPSIS.

The prioritised results indicated that environmental factors are significant but have a limited impact on other factors. The findings revealed that manufacturers' and suppliers' accountability for the end-of-life of their products is a vital factor in influencing RCWR. OG, EC, and PP factors were also found to have a moderating role and significant influence. New Zealand can benefit from prioritising small residential construction companies and incentivising waste profitability. Gov factors were found to be crucial for mandatory waste plan requirements at the project level. IT and SB factors have the lowest priority but addressing these aspects strategically could significantly impact other factors. Lastly, OP factors were assigned middle priority but had limited influence on other factors.

The results emphasised the need for a collaborative and comprehensive approach to optimise RCWR in the residential sector in New Zealand, suggesting a three-dimensional responsibility, including industry responsibility, supplier responsibility, and government responsibility. The industry's responsibility as a consumer drives the supplier's responsibility. The results revealed that a comprehensive educational approach for RCWR should be implemented to drive consumer demand in New Zealand. The government's responsibility includes incentivising RCWR, reviewing the building code, and imposing higher penalties on CW compliance. Incentives are found to be more effective than penalties in RCWR. Furthermore, the results highlighted the impact of workforce training and technical proficiency on RCWR performance, stressing the need for workforce retention strategies and support for small and medium construction businesses.

7.3 Significance and Contribution of the Research

The research significantly contributes to the existing body of knowledge, both theoretically and practically. Adopting an optimised comprehensive RCWR strategy is yet to receive widespread application and efficiency within the construction industry in New Zealand and beyond. This research, therefore, presents a groundbreaking effort to explore the influential indicators that impact the decision-making process while also emphasising the interrelationships among different categories of those indicators. To the best of the author’s knowledge, no previous study has attempted to investigate the decision-making process in RCWR while balancing the different interests of decision-makers in New Zealand. Due to the limited data on the RCWR and the related decision-making process, this research has successfully contributed to qualitative and quantitative data by providing a deeper understanding of CW reduction within the residential sector.

First, the investigation highlights and establishes the barriers and benefits of RCWR, the roles of stakeholders, and their interactions, offering valuable insights for academia and industry and presenting an opportunity to enhance their knowledge and familiarity with the topic. The framework directly aligns with the New Zealand waste strategy, which emphasises waste reduction but does not provide guidance on trade-offs when choosing among the most effective waste reduction strategies. The findings present validated indicators to support New Zealand's waste strategy goals for Phase One (now to 2030), Phase Two (2030 to 2040), and Phase Three (2040 to 2050). The proposed strategies in this research support embedding a circular economy to reduce waste through strategic planning, collaboration, investment, and education.

Second, the investigation successfully identified and ranked the factors that are most important to decision-makers, highlighting their degree of influence on RCWR. Unlike theoretical frameworks, the MCDM framework dynamically updates rankings and priorities for the decision-making criteria. Understanding these factors enables decision-makers to make informed and strategic decisions, improving the efficiency of resource allocation and tackling the critical elements that significantly impact the decision-making process. Third, understanding the interdependencies and relationships among the various aspects and relevant indicators assists in exploring different scenarios and evaluating the advantages and disadvantages of such cases. This understanding allows for the optimisation of RCWR practices, improves project outcomes, and tackles the complexities of choosing suitable RCWR strategies.

Last, the broader implications of the developed framework extend beyond New Zealand, complementing global tools such as the UN SDGs framework (e.g., SDGs 11 and 12). The methodological framework provides a replicable model for cities targeting waste reduction and circular economy transition. In addition, the developed framework complements existing LCA or cost-benefit models by adding this missing layer of comprehensively weighing multifaceted factors, such as innovative and technical, organisational, and social and behavioural factors, while balancing the diverse interests of all decision-makers.

7.4 Research Limitations and Future Directions

The current research has successfully achieved its primary aim and objectives; however, it is imperative to acknowledge the limitations. Initially, the research scope was explicitly confined to waste from the residential construction sector in New Zealand. While this focus allowed for a thorough exploration of RCWR, it may limit the generalisability of the findings to other waste types, such as demolition and renovation. The residential construction sector in New Zealand has unique characteristics due to geographical attributes and logistical issues, the building code, regulations, and design and construction methods, which could restrict the application of the research outcomes in a different context.

The sample characteristics demonstrated robustness and diversity, which supported the generalisability of the findings, backed by validated statistical analyses. However, the sample size may present a limitation due to the exploratory nature of this research and the wide range of factors that necessitate subject-matter expertise in RCWR. Further research can explore a larger sample size and refine the factors with different categorisations by examining them using simulation or modelling techniques other than the PLS-SEM and MCDM.

Although the primary focus of this research is on Auckland, the findings can be effectively applied to other regions in New Zealand. Areas experiencing rapid urban development and substantial residential construction, such as Hamilton, Wellington, Tauranga, and Dunedin, face similar goals and challenges in achieving CW reduction. The identified priority indicators, particularly in governance and economic dimensions, are likely relevant due to the same economic and regulatory environments across New Zealand. Moreover, indicators related to social, behavioural, or operational factors can be adjusted through local investigations to account for regional variations. Nonetheless, the developed framework supports informed decision-making from a broader perspective within New Zealand.

Future investigations could advance the research findings by building upon the mentioned limitations. This might involve conducting a thorough examination of different decision-making methods. Considering the research findings and conclusions above, the following recommendations are proposed:

- Future research could expand the geographical scope beyond Auckland or New Zealand to include a broader range of regions and contexts. This would enable a comparative analysis of RCWR practices, considering variations in industry dynamics, logistics and infrastructure, and regulation and policy requirements and priorities. A comprehensive identification of best practices and potential areas for improvement across different regions can be achieved by including diverse locations.
- The MCDM framework can be applied in a case study to evaluate and compare different scenarios. Alternatively, it can be automated using AI-generated tools or computer models that are adjusted and customised to meet the requirements of decision-makers. For instance, companies aiming to optimise waste performance onsite may benefit from using the operational criteria that consider waste sorting indicators. Ultimately, this enables these companies to design strategies for resource allocation according to their priorities and needs.
- Investigation of the supply chain factors that influence RCWR. When designing and planning a supply chain for construction materials, a case study could facilitate the application of multiple attribute decision-making techniques (MADM) to evaluate the efficiency of different supply chain scenarios. This involves considering the factors that influence the choice of materials with the potential for efficient RCWR. Following this approach can help evaluate the optimal supply chain design to achieve the best results for RCWR and compare mitigation strategies and policy scenarios.

- Collaboration in research and development to advance innovation and technology in RCWR and bridge the gap between research and industry. Future research can explore the different integration settings between industry and academia to enhance research benefits and practical applications, leading to the adoption of sustainable and efficient RCWR practices.

In conclusion, these recommendations can serve as a reference point for future research endeavours and provide insights into potential areas for improvement within RCWR.

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Appendix A: Ethics Approval

Ethics Approval (for interviews)

26 October 2022

Dat Tien Doan
Faculty of Design and Creative Technologies

Dear Dat Tien

Re Ethics Application: 22/258 A decision-making framework for residential construction waste reduction in New Zealand

Thank you for providing evidence as requested, which satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC).

Your ethics application has been approved for three years until 26 October 2025.

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.
8. 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: hadeel.albsoul@autuni.ac.nz ; esther.aigwi@aut.ac.nz

Ethics Approval (for questionnaire)

13 June 2023
Dat Tien Doan
Faculty of Design and Creative Technologies

Dear Dat Tien

Re Ethics Application: 23/133 A decision-making framework for residential construction waste reduction in New Zealand

Thank you for your responses to AUTEC's conditions. Your ethics application has been approved for three years until 13 June 2026.

Non-Standard Conditions of Approval

1. In the Information Sheet remove the sentence 'you have the right to withdraw at any point during the study', because as it is anonymous, they can only withdraw up until they submit the survey.

Non-standard conditions do not need to be submitted to or reviewed by AUTEC unless requested but must be completed before commencing your study.

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.
2. All public facing documents must have the AUTEC approval number and be of a high standard of spelling and grammar. Dates on the Information Sheet(s) and Consent Form(s) must be consistent.
3. Any amendments to the project must be approved by AUTEC prior to being implemented.
4. A progress report is due annually on the anniversary of the approval date.
5. A final report is due at the expiration of the approval period, or, upon completion of project.
6. Any serious or adverse events must be reported to AUTEC, this includes unforeseen issues that might affect continued ethical acceptability of the project.
7. AUTEC grants ethical approval only. You are responsible for obtaining management permission for access 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.

The application number and title need to be referenced on all correspondence related to this project. All forms are available online http://www.aut.ac.nz/research/researchethics

For any enquiries, please contact ethics@aut.ac.nz

(This is a computer-generated letter for which no signature is required)

The AUTEC Secretariat
Auckland University of Technology Ethics Committee

Cc: hadeel.albsoul@autuni.ac.nz ; esther.aigwi@aut.ac.nz

Ethics Approval (for focus group)

17 January 2024
Dat Tien Doan
Faculty of Design and Creative Technologies

Dear Dat Tien

Re Ethics Application: 23/133 A decision-making framework for residential construction waste reduction in New Zealand

Thank you for your responses to AUTEC's conditions.

Your ethics (focus groups) has been approved for three years until 17 January 2027.

Non-Standard Conditions of Approval

1. In the benefits section of the Information Sheet include the word 'not' in the following sentence 'may only be possible'.

Non-standard conditions do not need to be submitted to or reviewed by AUTEC unless requested but must be completed before commencing your study.

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.
2. All public facing documents must have the AUTEC approval number and be of a high standard of spelling and grammar. Dates on the Information Sheet(s) and Consent Form(s) must be consistent.
3. Any amendments to the project must be approved by AUTEC prior to being implemented.
4. A progress report is due annually on the anniversary of the approval date.
5. A final report is due at the expiration of the approval period, or, upon completion of project.
6. Any serious or adverse events must be reported to AUTEC, this includes unforeseen issues that might affect continued ethical acceptability of the project.
7. AUTEC grants ethical approval only. You are responsible for obtaining management permission for access 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.

The application number and title need to be referenced on all correspondence related to this project. All forms are available online http://www.aut.ac.nz/research/researchethics

For any enquiries, please contact ethics@aut.ac.nz

(This is a computer-generated letter for which no signature is required)

The AUTEC Secretariat
Auckland University of Technology Ethics Committee

Cc: hadeel.albsoul@autuni.ac.nz ; esther.aigwi@aut.ac.nz

Appendix B: Tools

Consent form- Participant (Interviews)

Project title: *A decision-making framework for residential construction waste reduction (RCWR) in New Zealand*

Project Supervisors: Dr Dat Doan and Dr Esther Aigwi

Researcher: *Hadeel Albsoul*

○ I have read and understood the information provided about this research project in the Information Sheet dated 25 October 2022.

○ 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, 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○

Participant's signature: ....

Participant's name: ....

Participant's Contact Details (if appropriate):

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Date:

Approved by the Auckland University of Technology Ethics Committee on 26 October 2022 AUTEC Reference number 22/258

Note: The Participant should retain a copy of this form.

Participant Information Sheet (Interviews)

Date Information Sheet Produced: 25 October 2022

Project Title: A decision-making framework for residential construction waste reduction in New Zealand

What is the purpose of this research?

The research aims to develop a decision-making framework for residential construction waste reduction in New Zealand. Conducting interviews is designed to achieve part of this aim by investigating factors influencing residential construction waste reduction in New Zealand. The researcher expects this research will be reported in articles and conference papers, ultimately resulting in the thesis, the proposed title of which is 'A decision-making framework for residential construction waste reduction in New Zealand'.

How was I identified and why am I being invited to participate in this research?

You are invited to participate in this research because you were identified as an expert in residential construction, and the dynamics of your decisions may impact residential construction waste reduction. In addition, the researcher obtained your contact information from publicly available sources, contacting your organisation, or other people who shared information about this research because they thought you might be interested in it. As an expert in the residential construction sector with an experience in waste management, you are in an ideal position to give valuable first-hand information from your expertise and perspective. The researcher is simply trying to explore your views on factors influencing residential construction waste reduction.

How do I agree to participate in this research?

To participate in this research, you must give your permission by signing the consent form before conducting the interview. You should read the consent form, sign and hand it back to the researcher, whether online or in person, before the interview. Please read the information provided in this sheet carefully to make an "informed" consent to participate. Your participation in this research is voluntary (it is your choice) and whether or not you choose to participate will neither advantage nor disadvantage you. You are free to refuse answering any question or withdraw from the study at any time. If you choose to withdraw from the study, then you will be offered the choice between having any data that is identifiable as belonging to you removed or allowing it to continue to be used. However, once the findings have been produced, removal of your data may not be possible.

What will happen in this research?

If you choose to take part in this research, you will participate in an interview. The interview will occur face-to-face, at your office, in nearby public space, or online for an estimated time of 30-60 minutes. I will contact you to arrange a mutually suitable time and location. The interview will involve me (the researcher, Hadeel Albsoul) introducing myself, answering any questions you have, and confirming your consent to participate. Then, I will begin the interview and will ask you to share your views about:

- Factors influencing residential construction waste reduction in New Zealand.
- Constraints in implementing residential construction waste reduction practices in New Zealand.
- Prioritising practices in residential construction waste reduction.
- Promoting residential construction waste reduction in New Zealand.

The interview will be semi-structured, conversational, and audio recorded. You will have an opportunity to review and correct the transcript of your interview within one month of receiving it via Email.

What are the discomforts and risks?

The researcher does not expect you to be exposed to discomfort or risk. However, you can announce your concerns to the researcher if you feel discomfort or risk. Your participation is voluntary, and you are free to withdraw at any time. To do this, please let the researcher know either during or after the interview. The researcher will remove any information you have provided up to that point from the data set if it is still possible. Once data analysis has commenced, removal of your data may not be possible.

What are the benefits?

The researcher does not expect any direct benefits to you personally from participating in this interview. However, your participation will be valuable to understanding the factors influencing residential construction waste reduction and learning about constraints and priorities for improving residential construction waste reduction in New Zealand. In addition, the researcher will send you the research findings (if you wish), which will benefit your knowledge of residential construction waste reduction and gain sustainability insights.

The researcher will benefit a PhD degree in Built Environment Engineering from AUT and academic publications. This research is for academic purposes only. The researcher is not employed and has never been employed in the New Zealand's construction industry. Therefore, there will be no conflict of interest with any of the participants.

How will my privacy be protected?

To ensure the highest level of confidentiality, a set of safeguards are in place to protect your privacy and the information you provide from unauthorised access, use, disclosure, modification, loss, and theft.

Your confidentiality will be managed throughout all stages of the research cycle. This includes the following measures:

- Consent forms will be digitally scanned and stored in a secured file on the AUT computer network accessed only by the research team. Hard copies of consent forms will be destroyed using the paper shredder. Soft copies of consent forms will be destroyed six years from the completion of data analysis.

- Data will be de-identified. After the interview, the audio recording will be transcribed, stripped of all direct identifiers, and replaced with a code and an attributed group name according to the participant's role. All audio recordings will be deleted immediately after completing transcription of responses.
- Participants will have the chance to review the transcribed data and confirm it through the member checking technique.
- The file of transcribed responses that links your real name and code number will be stored on a password-protected, secure device on the AUT computer network. All data will be destroyed six years from the completion of analysis. The research team will be responsible for ensuring that only the research team members use your data for the purposes mentioned in this information sheet.

What are the costs of participating in this research?

No monetary costs are associated with the interview. However, participating in this research requires the participant's time. The interview will occur face-to-face, at the participant's office, in nearby public space, or online for an estimated time of 30-60 minutes. The researcher will contact you to arrange a suitable time and location.

What opportunity do I have to consider this invitation?

If you are willing to participate, please sign the consent form and contact the researcher at hadeel.albsoul@autuni.ac.nz. Acceptance of participation is within one month from receiving this information sheet.

Will I receive feedback on the results of this research?

The researcher will transcribe the interview and send you a summary of the findings for member checking so you can resonate and validate the transcript. If you wish to receive the research results, the researcher will email them once published.

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 project primary supervisor, *Dr Dat Doan,* dat.doan@aut.ac.nz*.* Concerns regarding the conduct of the research should be notified to the Executive Secretary of AUTEC, *ethics@aut.ac.nz* , (+649) 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: Hadeel Albsoul, Email: hadeel.albsoul@autuni.ac.nz Room: WZ816, WZ Building, 34 St Paul Street, Auckland 1010, New Zealand

Project Supervisors Contact Details:

The primary supervisor: Dr Dat Doan, Email: dat.doan@aut.ac.nz Room WZ1213, WZ Building, 34 St Paul Street, Auckland 1010, New Zealand

The secondary supervisor: Dr Esther Aigwi, Email: esther.aigwi@aut.ac.nz Phone: 09 921 9999 extension: 6935 Room: WZ1202, WZ Building, 34 St Paul Street, Auckland 1010, New Zealand

Approved by the Auckland University of Technology Ethics Committee on 26 October 2022 AUTEC Reference number 22/258

Interviews Protocol

Summary of interview questions on factors influencing RCWR in New Zealand.

Category	Questions
Participants experience	Could you please introduce yourself and describe your professional background?
	How long have you been involved in residential construction?
	What is your experience level relative to RCWR?
General questions	What are the constraints in implementing RCWR practices?
	How can RCWR practices be prioritised?
	How can RCWR be effectively promoted in New Zealand? (what do you think is the way forward?
	Are there any differences between RCWR in Auckland and different regions of New Zealand?

Questionnaire: Evaluating factors influencing residential construction waste reduction in New Zealand.

Part 1: Information sheet

Introduction

Project Title: A Decision-making Framework for Residential Construction Waste Reduction in New Zealand

An Invitation: I am Hadeel Albsoul, a PhD researcher at Auckland University of Technology (AUT), supervised by Dr Dat Doan and Dr Esther Aigwi. We are investigating experts' views about factors influencing residential construction waste reduction in New Zealand.

What is the purpose of this research?
The research aims to develop a decision-making framework for residential construction waste reduction in New Zealand. This questionnaire is designed to achieve part of this aim by evaluating factors influencing residential construction waste reduction in New Zealand.

How was I identified, and why am I being invited to participate in this research?
The researcher invited you through publicly available sources such as LinkedIn or because you responded to the research advertisement presented in workshops/seminars/conferences.

To be eligible to participate, you should:

• Have a minimum of 3 years' experience in New Zealand's residential construction sector (home build, design and planning, procurement, project management);

• Have a dynamic role related to construction waste management in New Zealand (policy and regulation, research and development, construction waste operations).

How do I agree to participate in this research?
Your participation in this research is voluntary (it is your choice), and whether or not you choose to participate will neither advantage nor disadvantage you. Submitting this survey implies consent.

What will happen in this research?
You will be asked to rate your agreement on viewpoints regarding factors influencing residential construction waste reduction in New Zealand. The survey is anonymous; you and your organisation cannot and will not be identified from your responses. You have the right to withdraw until you submit the survey.

What are the discomforts and risks?
The researcher does not expect you to be exposed to discomfort or risk.

What are the benefits?
Participating in this survey will help us understand the factors influencing residential construction waste reduction in New Zealand. You will gain knowledge on sustainability and have access to research findings. The researcher benefits from a PhD and academic publications and has no direct employment in the construction industry.

How will my privacy be protected?

The survey is anonymous. Your responses will not and cannot identify you or your organisation.

What are the costs of participating in this research?

No monetary costs are associated with the survey. However, participating in this research requires a cost of time estimated at 20-30 minutes. You can complete the survey at various times and resume from where you left off rather than doing it all at once.

What opportunity do I have to consider this invitation?

The survey will be open for November 2023.

Will I receive feedback on the results of this research?

A URL link will be provided to bookmark to access a summary of the research findings once the survey is submitted.

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 Project Supervisor, Dr Dat Doan, dat.doan@aut.ac.nz, Phone: 09 921 9999 extension: 26326. Concerns regarding the conduct of the research should be notified to the Executive Secretary of AUTEC, ethics@aut.ac.nz, (+649) 921 9999 ext 6038.

Whom do I contact for further information about this research?

Please contact the research team as follows:

- Researcher Contact Details: Hadeel Albsoul, Email: hadeel.albsoul@autuni.ac.nz Room: WZ816, WZ Building, 34 St Paul Street, Auckland 1010, New Zealand
- Project Supervisor Contact Details:
    - Dr Dat Doan, Email: dat.doan@aut.ac.nz Phone: 09 921 9999 extension: 26362 Room WZ1213, WZ Building, 34 St Paul Street, Auckland 1010, New Zealand
    - Dr Esther Aigwi, Email: esther.aigwi@aut.ac.nz Phone: 09 921 9999 extension: 6935 Room: WZ1213, WZ Building, 34 St Paul Street, Auckland 1010, New Zealand

Approved by the Auckland University of Technology Ethics Committee on 13 June 2023, AUTEC Reference number 23/133.

Part 2: Participant characteristics

1.Professional background/Qualification____

2. Current job title____

3. Employee status

- Permanent.
- Contractor.
- Other: please specify ____

4. Employee regime

- ☐ Full-time.
- ☐ Part-time.
- ☐ Fixed term.
- ☐ Other: please specify____

5. Organisational portfolio

- Senior management.
- Middle management.
- Supervisor/team leader.
- Other: please specify ____

6. Company services____

7. Size of company

- SME.
- Large.

8. Professional experience (overall in years)

- <3
- 3-6
- 7-10
- 11-15
- 16-20
- >20

9. Residential construction-related job experience (years)

- <3
- 3-6
- 7-10
- 11-15
- 16-20

- >20

10. Highest degree
    - High school.
    - University Bachelors.
    - Master's.
    - Postgraduate diploma.
    - Doctorate.
    - Other: please specify ____
11. Location of experience
    - Auckland.
    - Other: please specify____

Part 3: Viewpoints about factors influencing residential construction waste reduction in New Zealand.

Operational factors

Q1 Please rate your agreement on viewpoints regarding design factors.

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
OP1.1 Design is the critical practice for effectively reducing waste in residential construction.	○	○	○	○	○
OP1.2 The greater degree of control over waste reduction is during the design and planning stage.	○	○	○	○	○
OP1.3 A waste reduction plan during the design and planning stages is essential for successful waste reduction.	○	○	○	○	○
OP1.4 Designing for waste, or waste reduction at design is rarely considered in the residential sector.	○	○	○	○	○
OP1.5 There needs to be more connection between the architect and the builder.	○	○	○	○	○
OP1.6 The design specifications may not align with the available dimensional materials in the market.	○	○	○	○	○
OP1.7 Designers can contribute by creating efficient and sustainable designs that use fewer materials.	○	○	○	○	○
OP1.8 Aesthetics requirements are of higher priority than waste reduction.	○	○	○	○	○
OP1.9 Custom-designed homes (bespoke design) generate more waste than modular homes.	○	○	○	○	○
OP1.10 Custom-designed homes (bespoke design) are desired more than modular homes in New Zealand.	○	○	○	○	○
OP1.11 Architects should understand the consequences of their choices and be equipped with the knowledge and options for waste reduction.	○	○	○	○	○
OP1.12 Architects often prioritise other design aspects, such as client requirements, over waste reduction.	○	○	○	○	○
OP1.13 Architects can only address waste if the client specifically requests or regulation	○	○	○	○	○

Q2 Please rate your agreement on viewpoints regarding material sourcing and procurement	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
OP2.1 There is a shortage of materials that offer improved end-of-life outcomes or have a reduced environmental impact.	○	○	○	○	○
OP2.2 Affordability often plays a significant role when choosing materials that effectively reduce waste.	○	○	○	○	○
OP2.3 Matching design specifications with available material sizes is challenging.	○	○	○	○	○
OP2.4 Collaborating with construction teams and build partners is key to optimising material usage and reducing waste.	○	○	○	○	○
OP2.5 Limited locally sourced materials and lack of substitution options are the challenges to material choices in New Zealand.	○	○	○	○	○
OP2.6 Compliance with building code standards and regulations contributes to the limited choice of materials in New Zealand.	○	○	○	○	○
OP2.7 Government incentives are needed to encourage local production of materials.	○	○	○	○	○
OP2.8 Overordering of materials is often influenced by supply chain and logistics issues.	○	○	○	○	○
OP2.9 Waste reduction could be incorporated as a contractual or procurement requirement.	○	○	○	○	○
OP2.10 The focus should be on the materials currently being wasted the most.	○	○	○	○	○

Q3 Please rate your agreement on viewpoints regarding waste sorting and collection	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
OP3.1 Sorting waste on-site is seen as a standard practice for waste reduction.	o	o	o	o	o
OP3.2 Education about waste sorting is crucial in preventing contamination and improving waste reduction.	o	o	o	o	o
OP3.3 Active waste sorting on-site is crucial for facilitating materials recycling and reuse.	o	o	o	o	o
OP3.4 Limited space on-site, lack of incentives, and site footprint hinder effective waste sorting practices.	o	o	o	o	o
OP3.5 Space limitations make accommodating separate bins for different materials difficult.	o	o	o	o	o
OP3.6 Large construction sites may have more resources and capacity to implement waste sorting practices and trial different approaches.	o	o	o	o	o
OP3.7 Auckland provides better accessibility to sorting facilities, while rural regions may lack such options.	o	o	o	o	o
OP3.8 Creative solutions like smaller bins, tote bags, or well-fenced bins can help overcome space limitations and contamination issues.	o	o	o	o	o
OP3.9 Construction density adds complexity to waste reduction and may require frequent pick-ups and truck movements for waste collection.	o	o	o	o	o

Q4 Please rate your agreement on viewpoints regarding logistics and infrastructure.	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
OP4.1 The lack of proper infrastructure negatively affects waste sorting and diversion practices.	○	○	○	○	○
OP4.2 Storage of salvaged items for reuse is a limitation due to the need for secure places protected from environmental degradation.	○	○	○	○	○
OP4.3 On-site storage space is a concern, and off-site storage adds transportation, maintenance, and logistical challenges.	○	○	○	○	○
OP4.4 Strategies such as stockpiling, reverse logistics, and proactive planning can facilitate successful material reuse.	○	○	○	○	○
OP4.4 Establishing waste targets at the beginning of a project minimises the impact on timelines, budgets, and scopes.	○	○	○	○	○
OP4.5 Construction companies should be aware of waste management options in each region.	○	○	○	○	○
OP4.6 Local councils should provide information and infrastructure for waste reduction.	○	○	○	○	○
OP4.7 Waste removal trucks could combine separated items from different sites or take them to landfills instead of recycling facilities.	○	○	○	○	○
OP4.8 Recovered materials, especially those with heritage significance, make material reuse a preferable alternative to landfill disposal.	○	○	○	○	○

Q5 Please rate your agreement on viewpoints regarding data capture and waste performance.	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
OP5.1 Construction waste estimates vary among organisations due to assumptions and data quality differences.	o	o	o	o	o
OP5.2 Collaboration with waste operators is necessary to improve data capture and waste reporting.	o	o	o	o	o
OP5.3 Improving data quality helps to make informed decisions, understand the economic value of waste, and drive behaviour change.	o	o	o	o	o
OP5.4 Data helps to compare, evaluate, and enhance waste reduction efforts.	o	o	o	o	o
OP5.5 Setting waste reduction targets tied with rewards or bonuses can hold site teams accountable and improve waste performance.	o	o	o	o	o
OP5.6 Rewards and bonuses for waste performance should be provided along with education.	o	o	o	o	o
OP5.7 A data-driven approach helps drive behaviour change and sets targets for reducing construction waste.	o	o	o	o	o
OP5.8 Education about the importance of data capture and measurement enhances reporting on waste.	o	o	o	o	o

Q6 Please rate your agreement on viewpoints regarding the economic factors.	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
Ec1 The cost of waste reduction often outweighs the benefit.	○	○	○	○	○
Ec2 There is a common perception that waste has little to no economic value.	○	○	○	○	○
Ec3 Waste reduction practices, such as waste sorting, typically demand extra labour, which may result in added costs.	○	○	○	○	○
Ec4 Understanding waste reduction costs is crucial for justifying waste reduction implementation expenses.	○	○	○	○	○
Ec5 The increased cost of building hinders adopting waste reduction practices.	○	○	○	○	○
Ec6 Maintaining affordable housing can sometimes be challenging to balance with waste reduction costs.	○	○	○	○	○
Ec7 There is a lack of financial incentives available to help offset the costs of waste reduction practices.	○	○	○	○	○
Ec8 Limited profitability from waste restricts competition and market development to progress in waste reduction.	○	○	○	○	○
Ec9 As waste levy becomes more expensive, companies prioritise waste reduction and explore more sustainable alternatives.	○	○	○	○	○
Ec10 Incentivising manufacturers to create product recycling points and take-back schemes.	○	○	○	○	○
Ec11 There is a need for more waste operators to facilitate effective waste reduction practices.	○	○	○	○	○
Ec12 Financial incentives create competition and motivate companies to improve waste practices.	○	○	○	○	○

Q7 Please rate your agreement on viewpoints regarding the social and behavioural factors.	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
SB1 The interests in waste reduction depend on the education level and information available.	○	○	○	○	○
SB2 The perception of waste as a problem rather than an opportunity influences the attitude towards waste reduction.	○	○	○	○	○
SB3 Shifting the perception of waste from a problem to an opportunity requires education and incentivisation.	○	○	○	○	○
SB4 Willingness to change influence active waste reduction.	○	○	○	○	○
SB5 Awareness of waste reduction refers to the awareness of the scale of the waste problem and the available solutions.	○	○	○	○	○
SB6 Client awareness and education about waste pressures demand for waste reduction.	○	○	○	○	○
SB7 Waste reduction efforts require the involvement and education of everyone involved at all levels.	○	○	○	○	○
SB8 Younger workers are more willing to learn about waste reduction than older generation.	○	○	○	○	○
SB9 Practical education and exposure to real-life projects can enhance understanding of waste reduction.	○	○	○	○	○
SB10 Sustainability and waste reduction should be integrated into every role in the construction industry.	○	○	○	○	○
SB11 Overcoming challenges in waste reduction requires willingness, strategic planning, and learning from more advanced regions/countries.	○	○	○	○	○
SB12 Building a culture focused on waste reduction within the industry requires collective education and commitment.	○	○	○	○	○
SB13 Peer pressure can be leveraged to drive positive change in construction practices and waste reduction efforts.	○	○	○	○	○
SB14 Specialised training for site supervisors can effectively implement on-site waste reduction strategies.	○	○	○	○	○
SB15 Addressing ego-driven practices and behavioural issues is necessary for creating a culture of sustainability in the industry.	○	○	○	○	○

Q8 Please rate your agreement on viewpoints regarding the organisational factors.	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
OG1 Support from top management level influence successful waste reduction.	o	o	o	o	o
OG2 Organisations need to set targets for waste reduction.	o	o	o	o	o
OG3 Industry organisations in New Zealand require government support and assistance to meet waste reduction training needs.	o	o	o	o	o
OG4 A client's commitment to sustainability influences project requirements and encourages prioritising waste reduction.	o	o	o	o	o
OG5 Collaboration and partnerships within the industry drive innovation and inspire others to adopt sustainable practices.	o	o	o	o	o
OG6 Smaller residential construction companies often lack technical expertise.	o	o	o	o	o
OG7 External support can help bridge the knowledge gap for smaller companies.	o	o	o	o	o
OG8 There is limited availability of internal training programs for waste reduction in residential construction companies.	o	o	o	o	o
OG9 Assistance and guidelines in a clear blueprint or best practice references are needed to implement sustainable waste practices.	o	o	o	o	o

Q9 Please rate your agreement on viewpoints regarding innovative and technical factors.	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
IT1 Adopting the right technology in residential construction helps to reduce waste.	o	o	o	o	o
IT2Technology, such as BIM, 3D printing, and material passports, can influence waste reduction.	o	o	o	o	o
IT3 Developing a materials passport system could enhance waste reduction in residential construction.	o	o	o	o	o
IT4 Off-site manufacturing has the potential to advance residential waste reduction and efficiency in the future.	o	o	o	o	o
IT5 Off-site manufacturing is not widely implemented in smaller-scale projects.	o	o	o	o	o
IT6 Transportation challenges could limit adopting off-site manufacturing.	o	o	o	o	o
IT7 Constraints such as project size, customisation requirements, training needs, and cost currently limit the widespread adoption of off-site manufacturing.	o	o	o	o	o
IT8 Further research to address concerns about the safety and long-term performance of recycled materials increases confidence in their use.	o	o	o	o	o
IT9 Research and development are needed to develop markets for modular products, reusable materials, and new building materials.	o	o	o	o	o
IT10 The cost of research and development and the need for a system-level approach to supply chains are important considerations.	o	o	o	o	o
IT11 Building code compliance limit introducing innovative construction materials.	o	o	o	o	o
IT12 Innovative accreditation and labelling systems can promote sustainable practices and commitment to waste.	o	o	o	o	o

Q10 Please rate your agreement on viewpoints regarding environmental factors.	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
Env1 Creating public awareness about the environmental impact of residential construction practices is crucial for waste reduction.	o	o	o	o	o
Env2 Highlighting the impact of waste on New Zealand's natural beauty and finite resources inspires the behaviour towards waste reduction.	o	o	o	o	o
Env3 Improving lifecycle information for materials assist better eco choices.	o	o	o	o	o
Env4 Using materials to be reused or recycled and considering the carbon footprint are strategies to reduce environmental impact.	o	o	o	o	o
Env5 Manufacturers and suppliers should take responsibility for the end-of-life of their products.	o	o	o	o	o
Env6 Manufacturing and transportation of materials have a more significant environmental impact and carbon footprint than waste.	o	o	o	o	o
Env7 The responsibility for waste reduction lies with the entire supply chain.	o	o	o	o	o
Env8 Collaboration with manufacturers and suppliers to propose alternative materials with better end-of-life options.	o	o	o	o	o

Q11 Please rate your agreement on viewpoints regarding best practices.	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
PP1.1 There is a need to make waste reduction guidelines accessible and understandable at all levels.	o	o	o	o	o
PP1.2 Accessibility of best practices is limited, especially for smaller-scale builders.	o	o	o	o	o
PP1.3 Simplifying the message and making waste reduction accessible and uncomplicated increases the likelihood of adoption.	o	o	o	o	o
PP1.4 Creating a business case for good waste practices and highlighting financial benefits increases the likelihood of adoption.	o	o	o	o	o
PP1.5 Industry associations and respected industry leaders should actively showcase best practices and encourage voluntary actions.	o	o	o	o	o
PP1.6 Industry associations should provide clear guidance and practical recommendations.	o	o	o	o	o
PP1.7 Voluntary actions can encourage waste reduction across all scales and sectors even without regulatory requirements.	o	o	o	o	o
PP1.8 Adopting best practices is a proactive measure that can reduce waste and save costs.	o	o	o	o	o
PP1.9 Regulatory requirements ensure the adoption of best practices.	o	o	o	o	o

Q12 Please rate your agreement on viewpoints regarding circular practices.	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
PP2.1 Businesses operating under a linear model find it challenging to progress in waste reduction.	o	o	o	o	o
PP2.2 Most business models in the residential sector are entrenched in a linear "take-make-use-dispose".	o	o	o	o	o
PP2.3 Circularity is limited by the long lifespan of residential buildings and the challenge of predicting future needs.	o	o	o	o	o
PP2.4 New innovative products and company shift in perspective are needed to drive the transition toward circular business models.	o	o	o	o	o
PP2.5 Material take-back initiatives support diverting materials from landfills, promoting a circular economy, and creating a sustainable system.	o	o	o	o	o
FPP2.6 actors such as infrastructure limitations, lack of willingness, drive, and stakeholder interest limits circularity.	o	o	o	o	o
PP2.7 Addressing infrastructure needs is an opportunity to promote circularity in waste reduction practices.	o	o	o	o	o
PP2.8 Innovative construction methods, the development of new products, and material take-back schemes support the circular economy.	o	o	o	o	o
PP2.9 Upstream activities and design are crucial to unlock circularity in waste reduction.	o	o	o	o	o

Q13 Please rate your agreement on the following viewpoints regarding business processes in the residential sector.	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
PP3.1 Conducting standard analyses of business processes will help find the best methods to cut down on waste later.	o	o	o	o	o
PP3.2 Improving upfront processes in the early stages of construction projects, particularly in the design and planning phase, is essential.	o	o	o	o	o
PP3.3 Evaluating supply chain processes helps avoid over-specifying materials and reduces unnecessary waste.	o	o	o	o	o
PP3.4 Ensuring everyone in construction understands roles, responsibilities, and efficient waste practices.	o	o	o	o	o
PP3.5 Standard processes can simplify waste reduction efforts and increase compliance.	o	o	o	o	o
PP3.6 Setting clear expectations and dictating on-site waste management practices help pass the responsibility for waste reduction onto the supply chain.	o	o	o	o	o

Q14 Please rate your agreement on viewpoints regarding governance factors.	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
Gov1 Regulatory changes, such as changes to building codes are necessary for waste reduction.	○	○	○	○	○
Gov2 The building code has a minimum requirement for waste reduction practices.	○	○	○	○	○
Gov3 Compliance with building code requirements is a challenge to getting more choices in sustainable materials.	○	○	○	○	○
Gov4 Building code should support more sustainable materials without increasing costs.	○	○	○	○	○
Gov5 Penalties for non-compliance will drive progress towards waste reduction.	○	○	○	○	○
Gov6 Waste plans should be a mandatory requirement on the project level.	○	○	○	○	○
Gov7 A higher waste levy will force people to think about alternative waste disposal methods.	○	○	○	○	○
Gov8 Waste reduction through designing waste out is difficult to regulate, so educating designers is a better approach.	○	○	○	○	○
Gov9 Regulations are necessary but can be diluted during implementation.	○	○	○	○	○
Gov10 Implementing regulations for the Homestar rating tool is required to drive progress in waste reduction.	○	○	○	○	○
Gov11 Education and awareness should come before regulation.	○	○	○	○	○
Gov12 A good cost-benefit analysis to waste reduction is needed before implementing regulations.	○	○	○	○	○
Gov13 Regional differences in building codes exist, and material choices are based on availability, cost, performance, and compliance.	○	○	○	○	○
Gov14 Government should facilitate collaboration and partnerships in the residential construction and waste sectors.	○	○	○	○	○
Gov15 Reducing waste is difficult due to the cost and time of the project rather than regulations and compliance.	○	○	○	○	○
Gov16 A waste reduction holistic approach involving government support, workforce training, incentivisation, research, and education.	○	○	○	○	○

Gov17 Lack of standardisation contributes significantly to construction waste, particularly off-cut waste.	o	o	o	o	o

We thank you for the time you spent taking this survey. Your response has been recorded. Please bookmark this link https://academics.aut.ac.nz/dat.doan/publications to access the research findings once published.

Participant Information Sheet (Focus group)

Date Information Sheet Produced:

20 November 2023

Project Title: A decision-making framework for residential construction waste reduction in New Zealand.

What is the purpose of this research?

The research aims to develop a decision-making framework for residential construction waste reduction in New Zealand. This focus group is designed to achieve part of this aim by evaluating factors influencing residential construction waste reduction in New Zealand.

During the focus group discussion, you will be presented with information relevant to the factors influencing residential construction waste reduction in New Zealand. Then, you will be asked to answer some questions about it. The findings of this research may be used for academic publications and presentations.

How was I identified, and why am I invited to participate in this research?

The researcher purposefully invited you through publicly available sources such as LinkedIn for your significant knowledge and experience in residential construction waste or because you responded to the research invitation sent to you. To be eligible to participate, you must:

- Have experience in New Zealand's residential construction sector.
- Have a dynamic role related to reducing residential construction waste in New Zealand.
- Have a minimum overall experience of three years.

How do I agree to participate in this research?

Your participation in this research is voluntary (it is your choice), and whether or not you choose to participate will neither advantage nor disadvantage you. You agree to participate in the focus group discussion by signing the consent form. You will be asked to sign and return the consent form before the focus group. However, additional consent forms will be available at the focus group.

What will happen in this research?

The focus group discussion aims to improve the decision-making process in residential construction waste reduction performance-based practices in New Zealand. The focus group is designed in table discussion, each involving a small group of 3-5 participants to discuss this topic. The primary researcher (Hadeel) and the project supervisors (Dr Dat, Dr Esther, and Dr Ali) will lead the discussion to moderate and guide the conversation and ensure that all participants can share their thoughts.

What are the discomforts and risks?

The researcher does not expect you to be exposed to discomfort or risk. Your participation is voluntary (your choice), and you do not have to answer a question you do not want to. You can leave the focus group at any time without being disadvantaged. If you choose to leave, destroying some records of the focus group discussion you are part of may not be possible. In that case, you will be offered the choice between having any data identifiable as belonging to you removed or allowing it to continue to be used. However, once the findings have been produced, removal of your data may not be possible.

What are the benefits?

The researcher does not expect any direct benefits to you personally from participating in this focus group. However, your participation will be valuable to understanding the factors influencing residential construction waste reduction and learning about constraints and priorities for improving residential construction waste reduction in New Zealand. In addition, the discussion with other experts benefits your knowledge of residential construction waste reduction and helps you gain sustainability insights. The researcher will benefit from a PhD in Built Environment Engineering from AUT and academic publications. The researcher does not have direct employment in any construction industry in New Zealand but has done some academic research on "housing prices" and "construction waste management review" in New Zealand.

How will my privacy be protected?

The consent form and recorded responses will be given a code to ensure confidentiality. Your responses will not and cannot identify you or your organisation. All participants will consent to discussions in the focus group being confidential to the group and will agree to keep this information confidential. All data will be kept in an AUT-secured file and will be destroyed six years after the completion of data analysis.

What are the costs of participating in this research?

No monetary costs are associated with the focus group. However, participating in this research requires a time cost of three hours.

What opportunity do I have to consider this invitation?

A response to the invitation email should be received within two weeks of receiving the invitation.

Will I receive feedback on the results of this research?

You can indicate your wish to receive a summary of the research findings in the consent form.

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 Project Supervisor, *Dr Dat Doan, dat.doan@aut.ac.nz, Phone: 09 921 9999 extension: 26326*.

Concerns regarding the conduct of the research should be notified to the Executive Secretary of AUTEC, *ethics@aut.ac.nz* , (+649) 921 9999 ext 6038.

Whom do I contact for further information about this research?

Please contact the research team as follows:

Researcher Contact Details:

Hadeel Albsoul, Email: hadeel.albsoul@autuni.ac.nz Room: WZ816, WZ Building, 34 St Paul Street, Auckland 1010, New Zealand

Project Supervisors Contact Details:

- Dr Dat Doan, Email: dat.doan@aut.ac.nz
  Phone: 09 921 9999 extension: 26362 Room WZ1213, WZ Building, 34 St Paul Street, Auckland 1010, New Zealand
- Dr Esther Aigwi, Email: esther.aigwi@aut.ac.nz
  Phone: 09 921 9999 extension: 6935 Room: WZ1213, WZ Building, 34 St Paul Street, Auckland 1010, New Zealand

Approved by the Auckland University of Technology Ethics Committee on *17 January 2024*, AUTEC Reference number *23/133*.

Consent form- Participant (Focus group)

Project title: A decision-making framework for residential construction waste reduction in New Zealand

Project Supervisors: Dr Dat Doan, Dr Esther Aigwi

Researcher: Hadeel Albsoul

- I have read and understood the information provided about this research project in the Information Sheet dated 20/11/2023.
- I have had an opportunity to ask questions and to have them answered.
- I understand that the identity of my fellow participants and our discussions in the focus group are confidential to the group, and I agree to keep this information confidential.
- I understand that notes will be taken during the focus group and that it 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 while it may not be possible to destroy all records of the focus group discussion of which I was part, 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, removing 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○

Participant's signature: ....

Participant's name: ....

Participant's Contact Details (if appropriate):

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Date:

Approved by the Auckland University of Technology Ethics Committee on 17 January 2024 AUTEC Reference number 23/133

Note: The Participant should retain a copy of this form.

Activity 1 (Focus group)

Objective: To prioritise and rank the RCWR indicators to improve RCWR performance in New Zealand

Participant Information
1. What is your title/qualification?
2. What is your highest degree? ◯ Bachelor's ◯ Masters ◯ Doctorate ◯ Postgraduate Diploma ◯ Other Please specify…………………………………………………………………………………
3. What is the size of your professional organisation? ◯ Small to Medium Enterprise (6 to 49 employees) ◯ Large (50+ employees) ◯ Other Please specify…………………………………………………………………………………
4. Which of these levels best describes your position within your organisation? ◯ Entry to middle Level ◯ Senior Level ◯ Supervisory Level ◯ Other Please specify…………………………………………………………………………………
5. Which of the following best describes your organisation's services? ◯ Government ◯ Architectural and design ◯ Waste management ◯ Construction and consultancy ◯ Research and commercialisation ◯ Other Please specify…………………………………………………………………………………
6. What is your current employee status (please choose all that apply): ◯ Permanent ◯ Contractor ◯ Full-time

◯ Part-time ◯ Other Please specify……………………………………………………………………………………….
7. Have you worked in Auckland at least within the last three years? ◯ Yes ◯ No
8. How many years have you worked in residential construction? ◯ <3 ◯ 3-6 ◯ 7-10 ◯ 11-15 ◯ 16-20 ◯ >20
9. How long have you been in work related to residential construction waste? ◯ <3 ◯ 3-6 ◯ 7-10 ◯ 11-15 ◯ 16-20 ◯ >20

Activity 2: Ranking of aspects and factors (Focus group)

Please rate the aspects and their related factors based on their importance in enabling residential construction waste reduction in New Zealand.

Very low (VL)=1, Low (L)=2, Medium (M)=3, High (H)=4, Very high (VH)=5

Note: Weighting and scoring results for aspect ranking is from the highest (1) to lowest (8)

		Weighting and scoring results			Balanced interests	VL	L	M	H	VH
		A	B	C						
Aspect1: Operational (OP)		4	1	7	2					
OP1	Design is the critical practice for effectively reducing waste in residential construction.	34%	0%	1%	19%					
OP2	Designing for waste, or waste reduction at design is rarely considered in the residential sector.	30%	30%	1%	37%					
OP3	There needs to be more connection between the architect and the builder.	27%	34%	1%	41%					
OP4	The design specifications may not align with the available dimensional materials in the market.	30%	100%	4%	100%					
OP5	Aesthetics requirements are of higher priority than waste reduction.	30%	30%	1%	37%					
OP6	Custom-designed homes (bespoke design) generate more waste than modular homes.	100%	30%	2%	76%					
OP7	Collaborating with construction teams and build partners is key to optimising material usage and reducing waste.	34%	34%	1%	41%					
OP8	Limited locally sourced materials and lack of substitution options are the challenges to material choices in New Zealand.	46%	30%	4%	76%					
OP9	Overordering of materials is often influenced by supply chain and logistics issues.	30%	46%	4%	76%					
OP10	Waste reduction could be incorporated as a contractual or procurement requirement.	34%	14%	1%	28%					
OP11	Sorting waste on-site is seen as a standard practice for waste reduction	34%	34%	0%	24%					
OP12	Space limitations make accommodating separate bins for different materials difficult.	46%	30%	100%	99%					
OP13	Construction density adds complexity to waste reduction and may require frequent pick-ups and truck movements for waste collection.	46%	30%	4%	76%					
OP14	The lack of proper infrastructure negatively affects waste sorting and diversion practices.	100%	30%	1%	59%					
OP15	Establishing waste targets at the beginning of a project minimises the impact on timelines, budgets, and scopes.	0%	34%	0%	0%					
OP16	Local councils should provide information and infrastructure for waste reduction.	14%	34%	1%	32%					
OP17	Recovered materials, especially those with heritage significance, make material reuse a preferable alternative to landfill disposal.	14%	34%	1%	28%					
OP18	Collaboration with waste operators is necessary to improve data capture and waste reporting.	27%	34%	1%	37%					
OP19	Rewards and bonuses for waste performance should be provided along with education.	34%	27%	1%	37%					
Aspect2: Economic (EC)		1	5	5	5					
EC1	The cost of waste reduction often outweighs the benefit.	16%	100%	100%	29%					
EC2	Understanding waste reduction costs is crucial for justifying waste reduction implementation expenses.	20%	20%	0%	5%					
EC3	The increased cost of building hinders adopting waste reduction practices.	100%	16%	100%	29%					
EC4	Limited profitability of waste restricts competition and market development to progress in waste reduction.	100%	100%	100%	100%					

EC5	As waste levy becomes more expensive, companies prioritise waste reduction and explore more sustainable alternatives.	20%	0%	51%	5%					
EC6	There is a need for more waste operators to facilitate effective waste reduction practices.	0%	20%	51%	5%					
EC7	Financial incentives create competition and motivate companies to improve waste practices.	20%	14%	38%	11%					
Aspect3: Social and behavioural (SB)		8	7	3	8					
SB1	The interest in waste reduction depends on the education level and available information.	0%	40%	0%	16%					
SB2	The perception of waste as a problem rather than an opportunity influences the attitude towards waste reduction.	100%	100%	100%	100%					
SB3	Shifting the perception of waste from a problem to an opportunity requires education and incentivisation.	1%	34%	0%	20%					
SB4	Willingness to change influence active waste reduction.	0%	40%	31%	14%					
SB5	Awareness of waste reduction refers to the awareness of the scale of the waste problem and the available solutions.	0%	40%	0%	11%					
SB6	Client awareness and education about waste pressures demand for waste reduction.	0%	0%	0%	0%					
SB7	Waste reduction efforts require the involvement and education of everyone involved at all levels.	1%	40%	31%	25%					
SB8	Younger workers are more willing to learn about waste reduction than older generation.	0%	40%	0%	16%					
SB9	Practical education and exposure to real-life projects can enhance understanding of waste reduction.	1%	40%	0%	20%					
SB10	Sustainability and waste reduction should be integrated into every role in the construction industry.	1%	40%	31%	22%					
SB11	Overcoming challenges in waste reduction requires willingness, strategic planning, and learning from more advanced regions/countries.	1%	40%	0%	20%					
SB12	Building a culture focused on waste reduction within the industry requires collective education and commitment.	1%	40%	31%	22%					
SB13	Peer pressure can be leveraged to drive positive change in construction practices and waste reduction efforts.	1%	40%	0%	20%					
SB14	Specialised training for site supervisors can effectively implement on-site waste reduction strategies.	1%	40%	31%	22%					
SB15	Addressing ego-driven practices and behavioural issues is necessary for creating a culture of sustainability in the industry.	1%	40%	0%	20%					
Aspect 4: Organisational (OG)		5	3	4	4					
OG1	Support from the top management level influences successful waste reduction.	38%	20%	0%	23%					
OG2	Organisations need to set targets for waste reduction.	38%	20%	0%	23%					
OG3	Industry organisations in New Zealand require government support and assistance to meet waste reduction training needs.	0%	14%	0%	13%					
OG4	A client's commitment to sustainability influences project requirements and encourages prioritising waste reduction.	38%	14%	0%	19%					
OG5	Collaboration and partnerships within the industry drive innovation and inspire others to adopt sustainable practices.	0%	20%	0%	19%					
OG6	Smaller residential construction companies often lack technical expertise.	25%	100%	100%	100%					
OG7	External support can help bridge the knowledge gap for smaller companies.	0%	0%	0%	0%					
OG8	There is limited availability of internal training programs for waste reduction in residential construction companies.	100%	16%	1%	32%					
OG9	Assistance and guidelines in a clear blueprint or best practice references are needed to implement sustainable waste practices.	38%	14%	0%	13%					

Aspect 5: Innovative and Technical (IT)		6	8	6	7					
IT1	Adopting the right technology in residential construction helps to reduce waste.	20%	0%	0%	27%					
IT2	Technology, such as BIM, 3D printing, and material passports, can influence waste reduction.	14%	38%	31%	38%					
IT3	Developing a materials passport system could enhance waste reduction in residential construction.	0%	38%	0%	4%					
IT4	Off-site manufacturing has the potential to advance residential waste reduction and efficiency in the future.	0%	38%	31%	19%					
IT5	Off-site manufacturing is not widely implemented in smaller-scale projects.	36%	25%	100%	54%					
IT6	Transportation challenges could limit adopting off-site manufacturing.	100%	100%	19%	95%					
IT7	Constraints such as project size, customisation requirements, training needs, and cost currently limit the widespread adoption of off-site manufacturing.	16%	25%	100%	26%					
IT8	Further research to address concerns about the safety and long-term performance of recycled materials increases confidence in their use.	0%	38%	31%	19%					
IT9	Research and development are needed to develop markets for modular products, reusable materials, and new building materials.	14%	38%	31%	38%					
IT10	The cost of research and development and the need for a system-level approach to supply chains are important considerations.	14%	38%	31%	38%					
IT11	Building code compliance limit introducing innovative construction materials.	16%	25%	100%	26%					
IT12	Innovative accreditation and labelling systems can promote sustainable practices and commitment to waste.	20%	0%	0%	27%					
Aspect 6: Environmental (ENV)		7	4	1	1					
ENV1	Creating public awareness about the environmental impact of residential construction practices is crucial for waste reduction.	60%	100%	0%	40%					
ENV2	Highlighting the impact of waste on New Zealand's natural beauty and finite resources inspires the behaviour towards waste reduction.	60%	100%	100%	69%					
ENV3	Using materials to be reused or recycled and considering the carbon footprint are strategies to reduce environmental impact.	0%	0%	100%	0%					
ENV4	Manufacturers and suppliers should take responsibility for the end-of-life of their products.	100%	100%	100%	100%					
ENV5	The responsibility for waste reduction lies with the entire supply chain	100%	100%	100%	100%					
ENV6	Collaboration with manufacturers and suppliers to propose alternative materials with better end-of-life options	100%	100%	100%	100%					
Aspect 7: Process and Procedure (PP)		3	2	8	6					
PP1	There is a need to make waste reduction guidelines accessible and understandable at all levels.	25%	1%	1%	6%					
PP2	Accessibility of best practices is limited, especially for smaller-scale builders.	19%	100%	1%	14%					
PP3	Simplifying the message and making waste reduction accessible and uncomplicated increases the likelihood of adoption.	25%	1%	1%	6%					
PP4	Creating a business case for good waste practices and highlighting financial benefits increases the likelihood of adoption.	25%	1%	1%	6%					
PP5	Industry associations should provide clear guidance and practical recommendations.	25%	1%	0%	5%					
PP6	Voluntary actions can encourage waste reduction across all scales and sectors even without regulatory requirements.	0%	1%	0%	2%					
PP7	Adopting best practices is a proactive measure that can reduce waste and save costs.	25%	1%	0%	3%					
PP8	Regulatory requirements ensure the adoption of best practices.	25%	1%	1%	5%					
PP9	Businesses operating under a linear model find it challenging to progress in waste reduction.	100%	100%	100%	100%					

PP10	Most business models in the residential sector are entrenched in a linear "take-make-use-dispose".	19%	1%	1%	5%					
PP11	Circularity is limited by the long lifespan of residential buildings and the challenge of predicting future needs.	38%	2%	1%	10%					
PP12	New innovative products and company shift in perspective are needed to drive the transition toward circular business models.	16%	0%	0%	0%					
PP13	Material take-back initiatives support diverting materials from landfills, promoting a circular economy, and creating a sustainable system.	16%	1%	0%	4%					
PP14	Factors such as infrastructure limitations, lack of willingness, drive, and stakeholder interest limit circularity.	19%	1%	1%	5%					
PP15	Innovative construction methods, the development of new products, and material take-back schemes support the circular economy.	16%	1%	0%	4%					
PP16	Upstream activities and design are crucial to unlock circularity in waste reduction.	25%	1%	0%	4%					
PP17	Conducting standard analyses of business processes will help find the best methods to cut down on waste later.	16%	1%	0%	2%					
PP18	Improving upfront processes in the early stages of construction projects, particularly in the design and planning phase, is essential	25%	1%	1%	5%					
PP19	Evaluating supply chain processes helps avoid over-specifying materials and reduces unnecessary waste.	25%	1%	1%	6%					
PP20	Standard processes can simplify waste reduction efforts and increase compliance	25%	1%	0%	5%					
Aspect 8: Government (Gov)		2	6	2	3					
Gov1	Regulatory changes, such as changes to building codes, are necessary for waste reduction.	73%	0%	0%	37%					
Gov2	Compliance with building code requirements is a challenge to getting more choices in sustainable materials.	63%	54%	48%	51%					
Gov3	Penalties for non-compliance as a driver towards waste reduction.	73%	63%	37%	55%					
Gov4	Waste plans as a mandatory requirement on the project level.	73%	66%	47%	58%					
Gov5	A higher waste levy will force people to think about alternative waste disposal methods	73%	66%	47%	58%					
Gov6	Regulations are necessary but can be diluted during implementation.	55%	66%	48%	52%					
Gov7	Implementing regulations for the Homestar rating tool is required to drive progress in waste reduction.	0%	34%	0%	0%					
Gov8	The government should facilitate collaboration and partnerships in the residential construction and waste sectors	64%	63%	37%	52%					
Gov9	A waste reduction holistic approach involving government support, workforce training, incentivisation, research, and education	73%	66%	37%	57%					
Gov10	Lack of standardisation contributes significantly to construction waste, particularly off-cut waste	55%	66%	46%	53%					

Activity 3: Aspects influence relations (Focus group)

Please rate the aspects relationships based on their level of influence in enabling residential construction waste reduction in New Zealand.

No Influence=0 Low Influence=1 Medium Influence=2 High Influence=3 Very High Influence=4

	OP	ENV	EC	IT	PP	SB	OG	Gov
OP								
ENV								
EC								
IT								
PP								
SB								
OG								
Gov								

Summary of participants' profiles (Interviewees)

Participant code	Professional background	Current job title	Employee status	Employment regime	Organisational portfolio	Company services	Size of Company	Professional experience (years)	RCWR-related Job experience (years)	Highest Degree	Location of experience
P1	Engineering	Development Manager	Regular	Full-time	Senior management	Social housing provider	SME	7-10	3-6	Master's	Auckland
P2	Engineering	Technical Manager-Residential Construction	Regular	Full-time	Middle management	Process management	Large	7-10	3-6	Doctorate	Auckland
P3	Science/ Energy efficiency management	Waste planning advisor	Regular	Full-time	Senior management	Local government	Large	>20	7-10	Master's	Auckland
P4	Civil Engineering	Project manager-waste minimisation	Regular	Full-time	Team leader	Social housing provider	Large	7-10	3-6	University Bachelor's	Auckland/Overseas
P5	Civil Engineering	Associate Development Manager	Regular	part-time	Supervisor	Property Development	Large	11-15	3-6	University Bachelor's	Auckland
P6	Environmental engineering-LCA certified practitioner	Technical director	Regular	Full-time	Senior management	Environmental and sustainability advisory firm	SME	16-20	16-20	Doctorate	Auckland/Overseas
P7	Registered Architect	Sustainability Consultant	Regular	Full-time	Senior management	Environmental consultancy	SME	>20	>20	University Bachelor's	Auckland
P8	Science and Environmental Science	Project manager-waste and resource efficiency.	Regular	Full-time	Senior advisor-project management	Central government	Large	>20	>20	Postgraduate Diploma	Auckland
P9	Environmental engineering	Professor of Environmental Engineering and Research Director	Regular	Full-time	Director	Research	Large	>20	7-10	Doctorate	Auckland/New Zealand wide
P10	Building apprenticeship, Project Management	Builder-developer	Regular	Full-time	Director	Residential Construction	SME	>20	>20	Apprenticeship/Trade certificate	Auckland

P11	Mechanical Engineering/ Supply Chain Management	Lead Sustainability Engineer	Regular	Full-time	Team leader	Engineering consultation services	Large	11-15	7-10	Master's	Auckland/Overseas
P12	Business sustainability	CEO	Regular	Full-time	Executive management	Ecolabelling, compliance, and auditing	SME	>20	11-15	University Bachelor's	Auckland/Overseas
P13	Technological management	Transformation lead environment	Regular	Full-time	Technical leader	Industry-government collaboration-Advisory services	Large	>20	7-10	Master's	Wellington/New Zealand wide
P14	Communication Engineering	Construction innovation	Regular	Full-time	Senior management	Research and commercialisation	Large	>20	3-6	University Bachelor's	Auckland/Overseas/ New Zealand wide
P15	Project management	Design and innovation leader	Regular	Full-time	Leader	Strategic construction services-residential construction	SME	11-15	3-6	Master's	Auckland