External Research Report ER82 [2023]

Understanding waste generation in the New Zealand construction sector: Scoping study

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Executive Summary

This report provides a comprehensive overview of the current understanding and knowledge gaps concerning construction and demolition waste (C&D waste) in New Zealand. C&D waste is a significant contributor to landfill, accounting for approximately 40 percent. The primary objective of this research project was twofold: (1) to synthesize the existing literature and reports, we aim to construct a comprehensive systematic overview delineating the known and unknown aspects of the primary waste streams constituting construction waste in New Zealand, and (2) to pinpoint key issues hindering a substantial reduction in construction waste.

To achieve these objectives, the research team engaged in a multifaceted approach. Extensive reviews of literature and reports were conducted, allowing for the identification of pivotal waste streams intrinsic to C&D waste within New Zealand, as well as worldwide trends. Simultaneously, an in-depth exploration of the impediments to transformative change in waste reduction was undertaken. Integral to the research methodology were questionnaires and workshops with stakeholders representing the construction sector New Zealand. These interactions provided invaluable insights and collaborative solutions, enabling the refinement and focus of challenges uncovered during the research process.

This report's findings present a unified comprehension of C&D waste in New Zealand, delving into specific waste streams stemming from the dynamic and complex sector of residential construction activities in the country.The report lays the foundation for informed decision-making, and the research brings into sharper focus the requisite steps to be taken towards sustainable waste management practices in the construction sector.

Key findings

This research report comprises multiple chapters that elucidate various factors and strategies associated with C&D waste minimisation, both within New Zealand and on a global scale. Additionally, the report examines distinct waste streams – timber, concrete, steel, plasterboard, and packaging – within the specific context of New Zealand.

The findings of this study can be most effectively categorized into five key issues. It is important to note that these issues are not always entirely distinct from each other; there are instances where the issues intersect and exhibit interconnectedness.

Key issue 1: data gathering methodologies

The research findings indicate that estimates of C&D waste vary significantly, ranging from 30 to 50 percent, depending on the data source. The wide range prompts the question of whether more precise data is necessary. The variability arises from methodologies that involve analysing a meticulously detailed subset of waste and then extrapolating to approximate the overall quantity. This may adversely affect the sectors ability to quantify the impact of waste mitigation activities. Despite the relatively small proportion of waste analysed, the research team noted the high quality and impact of this approach.

Landfill sites in New Zealand employ a combination of well-established methods. These methods involve quantifying a detailed sample of mostly domestic waste and visually inspecting a much larger volume of waste. This amalgamation of methods is used to estimate the composition of landfill content. However, these methods have notable limitations. Firstly, they demand significant labour inputs. Secondly, unpacking and quantifying general waste, carries considerable health and safety risks. Thirdly, observational bias might influence the second method of visual inspection, because an observer may notice one type of material more and overlook other materials.

Case studies are commonly used for construction site waste analysis. They typically encompass on-site observations, interviews, and sometimes involve quantifying a detailed sample of waste from a skip. However, these approaches face limitations, including the extent to which a specific case study represents the norm and the potential for people and organisations to change their behaviour as they are being observed.

Quantifying waste within the supply chain is difficult. The supply chain is complex and distributed, involving numerous organizations and sources of materials and processing beyond New Zealand. This complexity, particularly concerning the tracking of toxic components, hinders accurate assessments. A comprehensive understanding of hazardous materials or chemicals used in material treatment is crucial when redirecting materials away from landfills for reuse, as this often requires additional manual processing. The relative invisibility of hazardous materials or chemicals deserves further attention.

Key issue 2: non-construction waste (supply chain / demolition etc.)

The research findings highlighted the presence of commendable waste mitigation efforts at some construction sites. However, these efforts primarily focus on addressing waste and excess generated during the construction process. Waste generated on construction sites is typically a heterogeneous mixture, necessitating meticulous logistical planning and, in some cases, allocating a significant portion of the site for waste sorting and temporary storage. The focus on waste generated on construction sites does not address two critical areas of waste generation that contribute significantly to on-site waste: (1) waste generated within the supply chain (including packaging materials) prior to delivery to the construction site, and (2) focusing on the construction site itself does not influence behaviour at the design stage, where, for example, decisions and choices often lead to standard materials cut into non-standard sizes creating waste.

It is important to acknowledge the growing trend of deconstruction as effective deconstruction can increase the amount and quality of materials that can be reused. However, the research lacks substantial evidence regarding the cost effectiveness of deconstruction versus demolition, particularly the cost of labour and health and safety factors. Similarly, while there is some research regarding the safety measures employed during deconstruction activities, there is little on safety and material handling and processing when these materials are reused.

Key issue 3: The cost paradigm

The construction industry in New Zealand has faced substantial challenges in the past decade. As a result, there have been ongoing endeavours to enhance productivity and cut building costs. Looking to successful instances in other sectors such as electronics and clothing, two discernible trends emerge. Firstly, when the cost of a product is reduced, it often leads to (1) a shorter product lifecycle and (2) a diminished capacity for repair or deconstruction for reuse. A similar pattern is now emerging in construction. For instance, there is a growing preference for adhesives over mechanical fasteners like screws. In the short term, this shift benefits construction practitioners by enabling faster installation and requiring fewer skills. However, it also leads to increased use of toxic components and makes the resulting composite harder to deconstruct for future reuse.

The changes in construction practice poses a formidable challenge, given that this cost- paradigm is pervasive and customary across industries. Most industries that prioritize cost reduction do so at the expense of factors such as durability and reusability. Ironically, these are precisely the attributes that the construction sector must uphold and, if possible, enhance.

Key issue 4: The problem of reuse

The problem of reuse encompasses multiple facets. First, while some case studies unequivocally indicate non-cost-effectiveness, others seemingly achieve such efficiency through unconventional labour sources like community participation, which entails minimal or no cost.

Secondly, the recertification of materials for integration into new building projects is not straightforward. Many companies opt for new materials because of material warranties and liability considerations. Consequently, despite digital platforms that offer avenues for sharing surplus materials, reuse of materials requiring recertification is limited. Some organisations offer 'buy back' schemes where material can be returned for reimbursement. However, these are limited in scale and geography. To achieve the paradigm shift needed to divert materials from landfills towards reuse, platforms such as civilshare.co.nz and other types of services need substantial expansion both in terms of scale and user engagement.

Key issue 5: The problem of aggregating material for reuse

In New Zealand, some construction organisations are making significant efforts to effectively manage waste and surplus materials. "Waste Champions" within the sector is becoming increasingly common, along with the availability of guidelines and plans designed to aid companies in their waste and surplus management endeavours. These initiatives do come with associated costs, which larger organizations appear capable of absorbing, leading to evident and quantifiable outcomes that indicate material redirection.

However, it's worth noting that the New Zealand building sector comprises around 80 percent of small and medium-sized enterprises (SMEs). Combined, these smaller entities generate substantial volumes of C&D waste. Moreover, they are dispersed across the country, making the sharing of resources a logistical challenge. Additionally, many SMEs might lack the scale necessary to justify the appointment of a dedicated waste manager and might find it difficult to dedicate time to thorough research into recycling and material redirection methods.

For a holistic shift towards material redirection and reuse that significantly reduces landfill, a feasible solution must be developed to address the specific needs of this segment within the building industry.

Actions

Action 1 (short-term): Addressing key issue one, it is noteworthy that data collection remains predominantly a manual process, leading to inherently approximate measurements. This poses challenges in validating and quantifying changes in construction processes or practices. It's recommended to investigate options for integrating automated and digital systems into the data gathering process to improve accuracy and scalability.

Action 2 (short-term): In relation to key issue two, a distinct pattern emerges with the prevalence of waste mitigation efforts focused on the construction site itself compared to the relatively limited mitigation activities earlier in the supply chain. As materials draw closer to the construction site, their composition becomes more intricate, rendering deconstruction for redirection and reuse progressively complex. An opportunity lies within the supply chain to tap into cleaner material streams. To advance this, the report recommends a systemic review of the supply chain to ascertain possibilities for waste stream redirection prior to its arrival on construction sites. Simultaneously, investigating waste-minimizing design strategies is encouraged, as a reduction in waste generated directly addresses the underlying problem.

Action 3 (long-term): Key issue three relates to the cost paradigm. Handling and disposing of construction waste incur costs that are integrated into construction tenders and contracts, and passed on to project funders. Incremental cost increases in waste management are likely to impact builders uniformly, thereby not significantly furthering waste reduction goals. The prevailing economic response to rising costs in one aspect of production is often a decrease in costs elsewhere. While this is a dominant cost paradigm globally, there is a growing recognition of alternative frameworks, including indigenous knowledge systems that offer diverse perspectives. Embracing concepts such as Mātauranga Māori could potentially foster innovative approaches to this challenge.

Lastly, addressing key issues four and five, which centre on the practical aspects of reuse and efficient material aggregation, both continue to rely on labour-intensive and costly manual methods. To achieve meaningful strides in redirecting materials from landfills, novel systems and approaches need to be developed that allow for scalability while mitigating labour intensity and expenses. Additionally, many in the industry feel behaviour change in this regard is difficult. With regular reports in the press regarding recycling actually going to landfill, doubt in the efficacy of efforts to redirect material for reuse can result in significant resistance to behavioural change. A national system for verifying the efficacy of pathways for reuse and redirection would simultaneously reduce the need for individual companies to do it, and additionally increase trust that these systems are delivering on redirecting waste from landfill.

In summary, a dynamic array of issues emerges, conducive to both short-term and long-term implementation strategies. In the immediate sense, the established building stock and prevailing practices are unlikely to undergo immediate transformation. Therefore, efforts must be directed towards devising approaches for redirecting materials from existing structures as they reach the end of their lifecycle. Conversely, the long-term perspective necessitates a shift away from design processes that overlook waste considerations and construction practices that lack deconstruction foresight. Furthermore, there exists a spectrum of challenges, some with readily available solutions and others without. The quantification and handling of construction waste involve substantial manual efforts, with companies independently developing, validating, and assessing their waste management techniques. There is potential for the integration of modern technologies like robotics, machine learning, and AI to aid in quantification and third-party validation. This contrasts with the entrenched economics of construction – the "cost-paradigm" as labelled here – for which immediate and obvious solutions are elusive, yet this underpins many of the aforementioned challenges.

However, amidst the complexity, the findings illuminate five distinct focal points demanding sustained focus, investment, and in-depth research. Addressing these key areas comprehensively, will pave the way for the systemic change essential to reduce the proportion of landfill attributed to construction waste.

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1. Introduction

The construction industry is among the most resource-intensive sectors globally (Ghaffar et al, 2020). In New Zealand waste from Construction and Demolition (C&D) accounts is the largest source of waste sent to landfill (MfE, 2022b). In Auckland, C&D waste is the most significant waste stream and is forecasted as the most prevalent waste stream in the future (MfE, 2021).

C&D waste minimisation reduces the environmental burden by minimising waste at the source or through recycling (Cruz et al., 2019). C&D waste minimisation also can create new job opportunities and promote advanced technologies to make Sustainable Construction (SC) a common practice (BRANZ, 2014). C&D waste is generated in different stages of material extraction, manufacturing, transportation, construction, repair and demolition. Therefore, the construction industry requires C&D waste minimisation interventions covering the whole life cycle of construction.

This report addresses the following questions:

- What are the main waste streams in C&D?
- Where is that waste produced, within the supply chain or in on-site activities?
- Why and what behaviour leads to waste generation within the supply-chain and construction process?
- How are different countries attempting to C&D waste generation
- What groups and initiatives actively reduce and remove waste streams, and what lessons can be learnt from their experiences, particularly in New Zealand

2. Definitional issues and C&D waste composition across regions

C&D waste differs between countries both in the definition of C&D waste and its proportions in those countries.

2.1 Definitions of C&D waste

There is no single definition of C&D waste in the literature. Countries, including NZ, Australia, and Germany, consider contaminated soil excavated during land clearance as C&D waste (Brennan et al., 2014). In contrast, the USA and Netherlands do not consider excavated soil as a part of C&D waste (USEPA, 2015, European Commission, 2016). Some of the differences have been attributed to traditional European construction methods, which use excavated soil to fill the embankments for road construction and hence do not consider it waste (Correia et al., 2016). In addition, excavated soil is often taken to other sites as a construction material, as is therefore considered a resource rather than waste (Williams, 2005).

The United Nations Environment Programme (UNEP), defines waste generated during the construction, renovation or demolition of any building construction as C&D waste (UNEP, 2019). For the European Commission, C&D waste is any waste generated due to the activities related to the construction sector and falls under the European list of waste. That list considers all potential waste materials, including but not limited to wood, concrete, brick, gypsum, paper, plastic, insulation material, tiles and ceramics (Eurostat, 2010). In New Zealand, the Ministry for the Environment (MfE) defines C&D waste as "waste materials from the construction and demolition of a building including the preparation and/or clearance of the site or property" (MfE, 2021, p 3).

Some research has widened C&D waste to include factors such as time and cost delays, quality, inefficient management, poor equipment selection and excess material consumption (Lu and Yuan, 2011). These factors can be categorised into three broad streams: labour, material, and machinery (Chen et al., 2018). All the perspectives aimed to consider C&D waste by environmental or productivity approach (Lu and Yuan, 2011). Both approaches introduce different perspectives to consider concerns to C&D waste generation, leading to C&D waste generation, and factors influencing its minimisation.

While C&D waste should include the broader factors beyond physical objects, this wider definition has not yet gained widespread adoption. This report therefore adopts the MfE's definition of C&D waste, "waste materials from the construction and demolition of a building including the preparation and/or clearance of the site or property" (MfE, 2021, p 3).

2.2 Construction waste composition differs between regions

As the climate, available resources and construction style differs across regions, the waste streams are different. Table 1 provides an overview of the C&D waste composition in different regions across the world.

Table 1: C&D waste composition in different regions

Region	Country	Waste streams	Reference
Australasia	New Zealand	Timber, plasterboard, metal, cardboard, plastics	(Auckland Council, 2019)
	Australia	Timber, concrete, metals, plastics, glass	(Zhao et al., 2022)
North America	USA	Wood, gravel, concrete, metal, drywall (plasterboard), brick and plastic	(Aslam et al., 2020)
	Canada	Wood products, asphalt, drywall (plasterboard), concrete and masonry	(Yeheyis et al., 2013)
South America	Brazil	Concrete, wood, bricks, mortar, masonry	(Nunes and Mahler, 2020)
	Chile	Concrete, wood, metal, plastic, brick	(Véliz et al., 2022)
UK	England & Wales	Concrete, timber, metals, packaging, masonry, asphalt	(Lawson et al., 2001)
	Scotland	Concrete, asphalt, soil, timber, metals	(Rao et al., 2007)
Europe	Spain	Concrete, timber, metal, plastic, masonry	(Mália et al., 2013)
	Denmark	Concrete and masonry, asphalt, wood, metal, gypsum, plastic	(Gálvez-Martos et al., 2018)
	Netherlands	Concrete, asphalt, metal, wood, rubble	(Zhang et al., 2020)
Africa	South Africa	Concrete, timber, rubble, glass, soil	(Berge and Von Blottnitz, 2022)
	Nigeria	Concrete, metals, wood, soil, rubble	(Aboginije et al., 2021)
Asia	China	Concrete, bricks, mortars, metal, plastic and wood	(Aslam et al., 2020)
	India	Concrete and masonry, wood, metal	(Ram and Kalidindi, 2017)
	Japan	Rubble, wood, glass, packaging, concrete	(Tsukui et al., 2015)

In Australia, bricks, concrete and masonry contribute up to 60% of total construction waste (Zhao et al., 2022). In the North American region, wood and its products, such as plywood, panels, and lumber, were reported as the most prevalent waste streams. Concrete is identified as one of the priority streams in most EU countries (Zhang et al., 2020). For example, in Spain, the most prevalent waste streams are Concrete (85%), Timber (11%), and Metal (2 %) (Mália et al., 2013). Further, in China, the overall annually sorted timber and steel are about 10% (by weight) of total C&D waste produced. On the other hand, in China concrete, bricks, blocks, mortar and masonry represent 90% of total C&D waste (Aslam et al., 2020).

Therefore, the study is focused on understanding six primary materials in construction: Timber, Plasterboard, Steel, Packaging (cardboard & plastic), and Concrete.

3. Factors influencing waste generation

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

3.1 Supply Chain

Literature on construction waste in the supply chain stage shows that the most significant sources of construction waste relate to overordering, waste from packaging and non-reclaimable consumables and poor storage and handling of materials (Roberts, 2019). In addition, poor site conditions and damage to the material during transportation produce significant construction waste (Udeaja et al., 2013). Furthermore, the behaviour of key individuals associated with a supply chain of construction materials with construction materials influences waste generation. A study conducted in the UK on five construction projects ranging from £25 million to over £100 million found that inadequate material stock control, lack of education among the workforce, and weak supply chain alliances with suppliers were the key factors contributing to waste generation during the supply chain stage (Dainty and Brooke, 2004).

Despite the ability of information and Communication Technology (ICT) to positively impact the supply chain and waste management, there can be obstacles to industry implementation (Mandičák et al., 2021). This can be due to complexity, limits to organisational capability or the need to tailor the ICT extensively. Moreover, while there is extensive ICT within the supply chain, there are limits to its vertical and horizontal integration throughout the supply chain, which may increase waste (Akinade et al., 2015). For example, the low level of BIM-based measures to minimise material waste is due to the limited ability to translate material waste minimisation knowledge to computational models that can be incorporated into existing BIM software (Akinade and Oyedele, 2019).

Construction material supply chains are fragmented, and waste minimisation attitude varies across occupational groups according to their policies and regulations (Udeaja et al., 2013). In addition, various factors, including high capital costs, lack of commitment from suppliers, client demands, and inadequate formal training, also influence supply chain waste. (Udeaja et al., 2013). Furthermore, lack of environmental standards in the organisational procurement framework, poor supplier selection criteria, relationship with suppliers and manufacturing and transportation cost of building materials influence waste generation (Ho et al., 2009).

3.2 Construction

Waste is generated during the construction stage. The prime factors influencing the waste during construction are a lack of material storage facility, malfunctioning machinery, poor construction techniques, and unwillingness to make changes to pre-design and design stages (Ali et al., 2019; Islam et al., 2019). In addition, lack of innovation during the pre-design stage and poor designers' decision-making during the design stage often results in high waste generation during the construction stage (Calvo et al., 2014).

C&D waste is increased through the lack of on-site sorting of waste materials or poor sorting. Successful on-site sorting, which is often facilitated through the use of multiple bins, can lead to reuse and recycling of waste materials (Auckland Council, 2020). Construction projects, however, often fail to recover waste successfully leading to a high level of waste contamination, which means the waste cannot be reused or recycled (Menegaki and Damigos, 2018; Auckland Council, 2020a), which increases the landfill burden. Sub-contractors often lack knowledge, particularly those engaged in cavity and cladding fixing, internal wall lining, and roof installing (Chen and Lu, 2017).

Construction industry practitioners have discussed the environmental impact of refurbishment waste in the context of repair and refurbishment waste, yet the environmental impact of refurbishment waste often does not receive equal attention as construction and is frequently neglected (Domingo, 2011).

Not all construction waste is equal, however. Construction waste from demolition, for example, using wood from a demolished building, is not the same as timber waste generated from virgin timber. Nor is waste that has been recovered from construction and demolished and refurbished. New Zealand. has a low demand for refurbished products in the secondary market as clients' preference for the use of virgin materials over refurbished materials (Ali et al., 2019). More work is required by construction industry practitioners and policymakers on refurbished waste and its benefits (Hossain et al., 2018).

3.3 Demolition

The demolition of buildings currently creates significant amounts of physical waste, comprising many types of materials (Vieira and Pereira, 2015). The composition of demolition waste plays a vital role in recycling and reducing waste: it easier to deal with waste from a demolished building if the materials are all the same, than for a building comprising different materials (Chen and Lu, 2017). Influences on demolition waste range from the conceptual design to the physical monitoring of demolition activities (Islam et al., 2019), as does the geographical location, building category and usage, and demolition budget (Zheng et al., 2017). In addition, the time allocated for demolition, on-site waste sorting, cultural resistance to diverting demolition waste, and illegal waste dumping contribute to increased waste generation (Menegaki and Damigos, 2018).

3.4 Low cost of sending C&D waste to landfill

Waste levies around the world vary significantly. In New Zealand disposal has become the first choice for industry practitioners due to the relatively low waste levy (Auckland Council, 2019). However, new levy rates will see this increase the cost of using landfill from NZ$20 per tonne of construction waste in 2022 to NZ$30 by 2024. Small projects also tend towards using landfill rather than waste management and recourse recovery plans (Auckland Council, 2019).

3.5 Toxicity

One of the risks associated with demolition waste and reused materials is a potential of harmful, toxic, carcinogenic, or endocrine disrupting compounds being either present or generated through these activities. Demolition waste can contain compounds which have been phased out of use since the construction, and are now recognised to be harmful to use. Good examples for this are asbestos and lead (Pb), which can both still be found in New Zealand older buildings (Petrović, 2017a). As the recognition of harmful impacts continually improves, the list of compounds recognised as risk continues increasing, which means that the range of issues to consider is continually growing. Good examples of more recently recognised issues are formaldehyde, commonly used in particleboard and other composite wood materials, and phthalate plasticisers which were commonly added to vinyl (Petrović, 2017b). Some of these compounds are proving challenging to fully remove, and formaldehyde is still in use, but in formulations with lower off gassing (Petrović, 2023). While demolition waste containing asbestos and lead is currently categorised as hazardous waste and there are existing processes for their safe disposal, there is less clarity on how to safely dispose of materials which contain the more recently recognised harmful chemicals, such as formaldehyde and phthalate plasticisers.

In addition to issues with the disposal of materials which contain harmful compounds, reuse and recycling can also exacerbate such issues. Through reuse, materials containing problem compounds could remain in use for longer (e.g. an element covered in historical lead paint), or new harmful compounds can be generated during the process of recycling. For example, heating and recycling of PVC can generate dioxins, which are a group of environmentally persistent toxic gases which contain chlorine and are difficult to detect (Petrović & Hammer, 2018). This could present a barrier for successful transition to circular economy.

Achieving circularity becomes especially challenging when dealing with confusing and contradicting information about what is the best path for diverting waste from landfills for certain materials. A good example of this is plasterboard. Plaster is theoretically ‘eternally’ recyclable material, which is why it was identified by the European Union (EU) as one of the construction materials which could achieve closed loop (EuroGypsum, 2015). Originally, plaster comes from naturally occluding gypsum, which when heated (calcinated) turns into a powder called plaster, which turns into solid gypsum after being mixed with water, and this process can eternally repeat. Synthetic plaster is made from by-products from coal-fired power plants and currently is phased out as part of reduction of reliance on coal burning (EuroGypsum, 2021). According to one of the largest manufacturers of plasterboard in New Zealand, this is not a common practice here (Winstone Wallboards, n.d.). While suitable for circular economy, plaster can be hazardous if disposed mixed with biodegradable waste where it breaks down into a range of substances, including hydrogen sulphide which is a hazardous flammable gas which is harmful for human and environmental health even in small concentrations (Gypsum to Gypsum, 2015). Therefore, in Europe plaster can be put only in landfills separated from organic matter, which adds to desirability of recycling plaster. However, in New Zealand to date much effort is put into incorporating plaster as a compost conditioner, with facilities available in a good range of larger New Zealand centres. This approach presents a range of limitations: plaster as the eternally recyclable material is lost; due to presence of organic matter in the compost hazardous vapours could still be generated; it is effective in supressing weeds which signals a potential ecotoxic impact; and only particleboard waste from construction is accepted for such processing, where direct reuse might be possible. Because of these limitations it is hard to see use of plaster in compost as the best path for diverting waste from landfills, especially within the context of international efforts to fully close the loop for this material. Therefore, more research is needed to evaluate if the use of plaster for compost should continue to be recommended, together with more effort to close the loop and potentially 'eternally' reuse plaster.

Although potential presence of toxic components in the C&D waste is not new, continual attention is needed to the contribute to decreasing toxicity instead of prolonging old issues, or developing new problems.

3.6 Secondary markets for C&D Waste

Secondary markets depend on the type of C&D waste. There are markets for timber as a biofuel, soil and rubble for quarry filling and plasterboard for soil conditioner, although as discussed later in the report, use of plasterboard as a soil conditioner is ill advised due to toxicity concerns. Materials such as polystyrene and plastic packaging waste, however, have a limited secondary market (Low et al., 2020).

Recycling infrastructure and capacity is a significant driver of accessing secondary markets. While the Auckland region has more recycling plants to process C&D waste than other regions, the scale of infrastructure is small, and the plants are often overwhelmed with waste meaning a state-of-the-art recycling infrastructure is required (Auckland Council, 2019). In addition, NZ construction industry practitioners are not effectively practising product stewardship schemes. Stakeholders do not share waste minimisation responsibilities equally: for example, it is often claimed that subcontractors' role in waste collection, sorting and recovery is lacking (Wu et al., 2019).

Resource recovery and margins on second-life products also influence recovery of waste. The returns on investment in C&D waste recovery are low. For instance, materials such as glass and carpets when recovered generate low profits (Auckland Council, 2019). As a result, other waste streams can be prioritised over handling services C&D waste. Deconstruction of buildings, as a practice, have limited drivers and incentives in New Zealand (BRANZ, 2019). Deconstruction in a building context is defined as 'activity performed at the end of the life cycle that allows efficient resource recovery of materials through reuse and recycling and recovery' (Auckland Council, 2019). Deconstruction aims to replace demolition with the objective of efficient use of resources with minimum waste. In addition, deconstruction promotes resource recovery plans and creates job opportunities at reuse and recycling facilities to make investment feasible (BRANZ, 2019). However, contractors often prefer demolition over deconstruction as they view the latter as a challenge: demolition requires less time, labour, cost, machinery and skills (Ajayi et al., 2017).

4. C&D Waste Minimisation Approaches

C&D waste minimisation is often guided by the need for a sustainable building environment and is considered a subset of waste management (Domingo and Luo, 2017). Different perspectives define C&D waste minimisation, and all are considered under two broad categories: i) at source; and ii) by recycling. In addition, on-site reuse and recovery are part of the recycling category (Gálvez-Martos et al., 2018; Ma et al., 2020). Some of the definitions of waste minimisation from both perspectives are listed in Table 2.

Table 2: Definitions of C&D waste minimisation

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

Table 2 shows that 'source' waste minimisation deals with materials before they become physical waste, while 'recycling' deals with materials after they become physical waste (Ma et al., 2020). Both steps are based on the same principle of waste elimination and are considered part of a waste management hierarchy (Gálvez-Martos et al., 2018). However, as Figure 1 demonstrates, waste minimisation at source is higher up the waste hierarchy and is preferred over recycling.

4.1 Waste Management Hierarchy

C&D waste minimisation approaches have evolved over the last few decades (UNEP, 2015). C&D waste minimisation approaches are divided into waste management hierarchy, regulations and guidelines, and Tools (USEPA, 2018). Because waste can be generated at any stage (design to end-of-life), more than one option for management is required (European Commission, 2016). A waste management hierarchy provides multiple options for waste minimisation and management. Figure 1 shows a generalised management hierarchy.

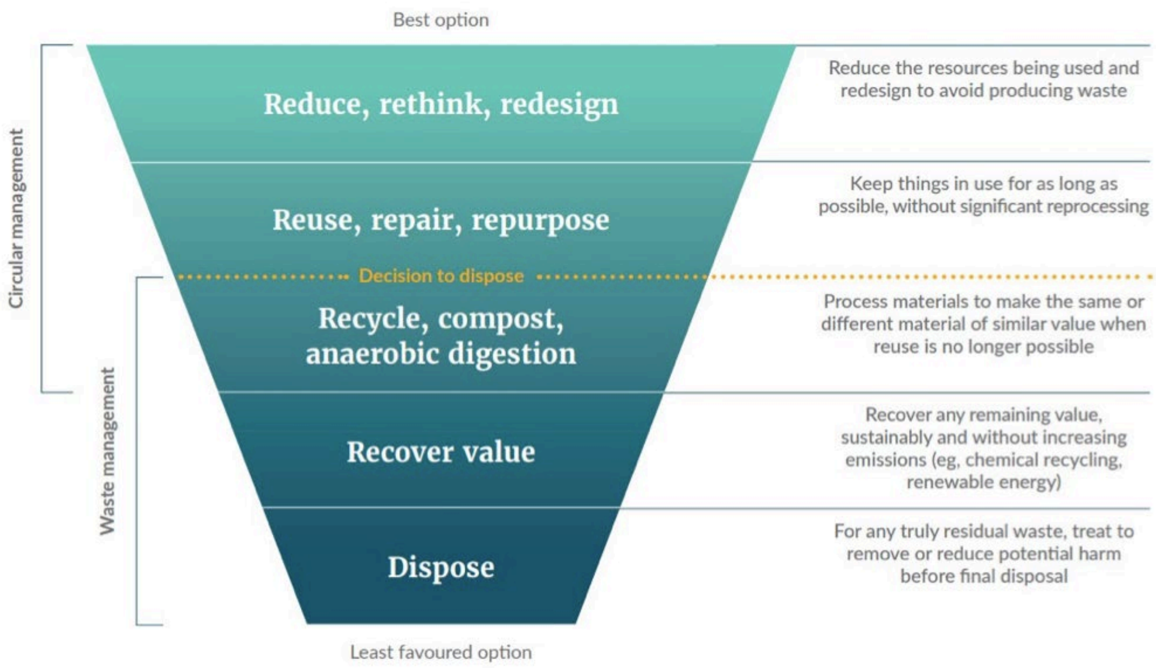

Figure 1: Waste management hierarchy (MfE, 2023)

The waste management hierarchy lays out possible environmental impacts of waste through different steps, ranging from reduction, which has fewer consequences, through to disposal, with more consequences (UNEP, 2015). In addition, the hierarchy guides the order of preference of action: reduction is the most preferred, with disposal as the least preferred (UNEP, 2013).

However, just as there is no one definition of C&D waste worldwide, there is also no on single waste management hierarchy. Table 3 sets out the waste management hierarchy in different regions throughout the world. New Zealand's version of the waste management hierarchy is similar to waste hierarchies in different world regions, as shown in Table 4. Table 4 demonstrates that New Zealand's version had a similar sequence to other waste hierarchies. The waste management hierarchy began with reduction and disposal or residual disposal at the bottom (MfE, 2015). Similar to Australia, New Zealand added 'Treat' before disposal or residual disposal (MfE, 2021).

Table 3: Waste management hierarchies in different regions

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

The following subsection overviews C&D waste minimisation approaches practised worldwide.

4.2 C&D waste minimisation approaches worldwide (regulations)

Different guidelines and regulations have been published around the world in an attempt to minimise C&D waste at different project stages. Table 4 shows the guidelines and regulations used worldwide for C&D waste minimisation.

Table 4: Guidelines and regulations for C&D waste minimisation in different regions

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

Region	Country	Provision for waste minimisation	Regulatory tools
			Ministry for Business, Innovation and Employment, Building for climate change programme (2021)

North America focuses on procuring materials though the use of regulatory tools to guide efficient regional waste procurement (Government of Canada, 1990). Efficient procurement allows suppliers to promote packaging reduction and timely delivery of quality-checked products within the allotted budget (Waste Reduction Act, 1990). As a result, on-site material waste was reduced by 10% (CIB, 2001).

Similar trends for waste minimisation are found in the South American region. However, regulations focus on waste generators (National Environment Council, 2002). As a result, responsibilities for waste minimisation are not equally shared among stakeholders. For example, in Brazil, when Resolution 307 was enacted by the National Environmental Council in 2002, the industry began to find viable solutions to C&D waste. However, the practice may be different to the theory. The Ministry of Education in Brazil conducted a case study on a seven-story residential construction project revealing that twice as much construction waste was generated as predicted (Maciel et al., 2016). Failure to minimise waste was due to a lack of waste management and control systems, the absence of a waste management plan, poor control over resource consumption, and lack of reuse (Maciel et al., 2016).

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

In the UK, all tendered construction projects above £300,000 (NZ$ 622,000) must have the Site Waste Management Plan (SWMP) before the execution of work (DEFRA, 2013). Although the UK's legislative requirement to carry out SWMPs has been repealed due to overly bureaucratic processes, contractual arrangements between contractor and client require them to be completed (Rose and Stegemann, 2018).

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

In Asia, particularly China and India, it is common to have regulations on building materials and their efficient procurement (Ministry of Housing and Urban Rural Development, 2010). The regulations help both countries to promote sustainable construction (Ministry of Housing and Urban Affairs, 2018). The Japanese construction industry has regulations on recyclable materials, standards, and environmental impacts of construction materials (Ministry of the Environment, 2004). The regulations offered a selection of sustainable materials and raised the recycling rate of construction waste from 42% in 1995 to 97% in 2011 (Liu et al., 2020).

The Australasian Procurement and Construction Council published a sustainable material procurement framework for Australia and NZ (Australian Procurement and Construction Council, 2007). The framework allows organisations to meet their needs for products, services and works and achieve value for money without negatively impacting the environment (Australian Government, 2009). New Zealand have also published a 'Procurement guide to reducing carbon emissions in building and construction' with similar goals (MBIE, 2021). The sustainable material procurement framework optimises resource consumption, introduces innovation in sustainability and adopts ethical practices (Australian Government, 2009). As a result, the Western Australian Government, the New South Wales Government and Queensland Government aligned their procurement goals with the framework (Tomossy and Alam, 2017). In contrast, the framework was criticised in NZ for its lack of social aspect. The Auckland Council's Procurement Strategy and Group Procurement Policy explicitly refer to social procurement to promote community economic development and reduce poverty (Menzies 2018).

4.3 New Zealand

In 1990, the New Zealand government introduced a National Waste Management Policy to minimise solid waste by applying reduction techniques (MfE,f 1997). The policy promoted recycling at the local level, and in 1992 it was revised to add a waste management hierarchy for achieving the best possible waste minimisation results (Auckland Regional Council, 2009). In addition, New Zealand's Waste Minimisation Act (2008) was enacted to offer product stewardship schemes to promote good design and diverting materials from landfill via reducing, reusing, recycling or recovery (WMA, 2008). While, as this report explains in later sections, there has been some via reduction, reuse, recycling and recovery, construction industry practitioners have not satisfactorily implemented Parliament's vision of the Waste Minimisation Act (Gade et al, 2020).

New Zealand has a reasonably long history of introducing guidelines and regulations to minimise C&D waste. One of the earliest examples is the Forests Act (1949), which regulated timber use to minimise timber waste. In addition, indigenous timber provisions in the Forests Act required any business or work using timber to be environmentally sustainable (Forests Act, 1949). By the early 1990s, Parliament increasing concerns over resource efficiency saw the passing of the Resource Management Act (RMA, 1991) and building regulations (Building Act, 1991).

Between 2000 and 2008 a range of waste management guidelines were published in an attempt to divert waste from the landfill, they include the guidelines for landfill (MfE, 2000) and clean fill (MfE, 2002a). In addition, a waste strategy was introduced in 2002 to manage and minimise waste effectively and move New Zealand towards zero waste (MfE, 2002b). However, the landfill guidelines were designed explicitly for Municipal Solid Waste (MSW). The clean fill guidelines sought to avoid site contamination and leachate generation as clean fills received C&D waste in increasing quantities. The landfill and clean fill guidelines were updated with 'Technical Guidelines for Disposal' to provide detailed technical guidance to design, operate and monitor the five classes of landfill (WasteMINZ, 2018).

In 2008, the WMA was passed to encourage waste minimisation and reduce waste disposal. The WMA includes provisions that could impact C&D waste, such as waste levies, product stewardship, and the role of territorial authorities in promoting waste minimisation and monitoring. In addition, local Government was required to have a Waste Management and Minimisation Plan (WMMP) and conduct sexennial waste assessments, which tracked progress on previously set goals and targets for the future.

Table 5 provides an overview of the WMMPs and waste assessments for city councils that had updated their plans where construction activities and resultant C&D waste generation were higher in those areas. Of the 67 councils in NZ, 13 are city councils, like the Auckland Council, and the rest are district councils that look after small towns and rural areas (Localcouncils.govt.nz, 2019).

Table 5: The WMMP with C&D waste minimisation actions for different city councils (in the order they published their first WMMP)

Territory/ Region/ Council	**First WMMP (year)**	**Waste Assessment (year)**	**Second WMMP (year)**	**C&D waste actions set in the first plan**	**C&D waste actions assessment**	**C&D waste actions in the second plan**
Tauranga	2010	2016	2016	Regulations for recyclable materials Encourage the reuse of materials	Partly achieved	Set up waste minimisation learning units Optimise resource consumption
Wellington	2011	2016	2017	Set regulations for clean fills Provide support to businesses practising SC	Not achieved	Set up resource recovery units Rethinking manufacturing building products
Auckland	2012	2017	2018	Set up resource recovery units Promote Resource Efficiency through REBRI guidelines	Partly achieved	Promote Redesign and repurpose. Practice of deconstruction
Hamilton	2012	2017	2018	Monitoring WMMP Improve landfill diversion	Not achieved	Implement DoW requirements Stakeholder collaboration
Hawkes Bay	2012	2017	2018	Promote management hierarchy Maximise resource recovery	Unable to measured	Recycled material guidelines. Develop community awareness
Palmerston North	2012	2018	2019	Set up recycling units Efficient waste collection	Partly achieved	Community engagement. Precise waste quantification
Nelson	2012	2017	2019	Promote REBRBI guidelines and the Homestar[1] programme Practice source reduction	Partly achieved	Financial support for community-led projects. Promote circular economy
Christchurch	2013	2019	2020	Set regulations for clean fills Promote the reuse of materials	Partly achieved	Application of deconstruction to improve resource recovery
Dunedin	2013	2018	2020	Set up resource recovery units	Partly achieved	Promote use of an online toolkit.

Table 5 shows that Tauranga City Council was the first Council to publish a WMMP with C&D waste goals (Tauranga City Council, 2010). Christchurch (Christchurch City Council, 2013) and Dunedin (Dunedin City Council, 2013) city councils were the last. Most city councils partly achieved the targets

[1] https://www.nzgbc.org.nz/homestar

set in their first WMMP, but targets remained unachieved or unable to measure for some city councils (Tauranga City Council, 2016). Reasons city councils were unable to achieve the targets included less control on waste generation than industry, collaboration with stakeholders, resource recovery infrastructure, and poor quantification of C&D waste (Palmerston North City Council, 2019). Future targets of all city councils are focused on precise waste quantification, expansion of resource recovery networks, and promotion of a circular economy (Auckland Council, 2018).

The New Zealand government has implemented a waste levy through the WMA to generate revenue, promote and achieve waste minimisation, and internalise the external costs associated with waste. Local councils have advocated increasing the waste levy to increase financial incentives and support innovative waste minimisation businesses (Auckland Council, 2018). The Waste Minimisation (Calculation and Payment of Waste Disposal Levy) Regulations 2009 set out the current waste levy fees. From July 2023 the waste levy fee will be (MfE, 2022a):

- Municipal landfill: $50 per tonne (increasing to $60 per tonne in July 2024)
- C&D waste landfill: $20 per tonne (increasing to $60 per tonne in July 2024); and
- C&D clean fill (and managed fill): $10 per tonne

Currently, the New Zealand government is obtaining waste data from a selection of transfer stations and disposal data covering total quantities from MSW landfills. The aim is to improve the waste assessment through the levy and use the levy fund to support more widely innovative waste minimisation businesses (MfE, 2022a).

An example of how the levy is used is from the Auckland Council, which uses the waste levy as a funding mechanism to support businesses (Auckland Council, 2018). The Council's Waste Minimisation and Innovation Fund is allocated to innovative initiatives that minimise waste. In 2020 the Auckland Council funded 51 waste minimisation initiatives for $650,000. The C&D waste stream received 20% of the funds for five initiatives (Auckland Council, 2020b). The initiatives were intended to minimise waste from the design, construction and demolition stages. Waste minimisation at these stages was identified as a critical action in the 2018 WMMP (Auckland Council, 2018).

In addition to the guidelines and regulations enforced by governmental organisations, non-governmental organisations, including BRANZ and NZGBC (New Zealand Green Building Council), have produced C&D waste minimisation guidelines and goals dedicated to helping industry and community (BRANZ, 2014). For example, the Auckland council and BRANZ collaborated to attempt to resolve the C&D waste issue and formed the REBRI (Resource efficiency in the building and related industries) programme in 1995 (BRANZ, n.d.a). REBRI has published a template Site Waste Management Plan (SWMP) to guide contractors. NZGBC is promoting SWMPs by awarding up to five credits where the following are demonstrated during construction and refurbishment (NZGBC, 2021):

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

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

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

The guidelines outline a range of strategies for minimising C&D waste at various stages of a project, including involving stakeholders early on, using "Just in Time" (JIT) for material procurement, identifying markets for recycled materials at an early stage, conducting on-site waste sorting, and providing incentives for waste minimisation (e.g., offering morning tea or coffee) (BRANZ, 2014). In addition, source separation, efficient resource consumption, and resource recovery are additional mechanisms to reduce waste (Easton, 2012).

In addition to guidance, the REBRI programme provided waste minimisation tools, including a resource routing calculator, waste management plan, recycling directory, and waste transfer form (BRANZ, n.d.a). These tools helped quantify waste and understand how products convert it into waste over their life cycle (NZ Ecolabelling Trust, 2019).

The application of Lean Construction tools and Supply Chain Management (SCM) for minimising C&D waste was not standard in NZ. However, case studies suggested that lean tools helped minimise C&D waste through source reduction and on-site sorting (Vilasini, 2014). In addition, the practice of SCM for material procurement promoted environmental benefits (Samarasinghe, 2014). The Building Information Modelling (BIM) adoption for C&D waste minimisation started in the 1980s with a growing interest in NZ. However, the uptake of BIM in NZ is slow due to a lack of understanding, difficulty in implementation, and low interest from industry practitioners (Doan et al., 2020).

4.4 C&D waste minimisation tools

The construction industry uses different tools across the world to minimise waste, predict quantities of waste, and forecast recyclable content. For example, DoWT-B (Designing out waste tool for buildings) helps contractors identify opportunities to design out waste, record design solutions and calculate their impact on waste (Gupta et al., 2020). The Net Waste Tool focuses on environmental and commercial waste costs and calculates the potential waste quantities throughout the project (Akinade et al., 2018). The Net Waste Tool can also be used to predict quantities of recyclable materials and optimise their consumption (Akinade et al., 2018).

Some other tools, such as Value Stream Mapping (VSM), BIM, Linear Programming (LP), and Vector Programming (VP), are also used to minimise C&D waste in the design stage and divert it from landfill in construction and demolition stage. For example, the application of VSM reduced the material lead time by 30 % and the total cost of a project by 20 % (Gunduz and Naser, 2019). BIM can also be used to find drawing inefficiencies, optimise resource consumption and promote the reuse of resources (Baros, 2016). For example, a case study conducted on a residential unit in South Korea showed that BIM identified and categorised design errors and reduced construction waste by 15.2% in that study (Won et al., 2016).

LP models can minimise the projects' time and cost by focusing on material selection, procurement and handling, and workforce management (Salim, 2010). In a case study on 23 residential buildings in Brazil, the model obtained an accuracy of 64% in the development phase and 67% in the validation phase (Maués et al, 2020). With these results, the waste manager was able to generate a baseline graph to indicate the waste volume to be reused or recycled (Maués et al, 2020).

VP is a multi-objective mathematical model used to optimise a process (Rudloff et al., 2017). A case study of a residential project showed that VP models reduced the total number of sheets required to construct a building and minimise waste. VP model provided multiple solutions to minimise scrap area, i.e. off-cuts with a maximum shared edge. The optimised solution reduced the scrap area by 17.73 m^2 and maximised the shared edge by 512.18 m. VP models optimise resource consumption to maximise reuse and minimise waste (Connor and Siringoringo, 2017). For the Physical Science Building project at the University of Central Florida, the VP model first calculated the total environmental impacts of various waste management options: recycling, conventional landfilling and incineration (Kucukvar et al., 2016). A compromise programming model was then used to determine the optimal recycling strategy considering environmental and economic impacts (Kucukvar et al., 2016). The findings predicted that cardboard waste could be reduced by 100% and plasterboard by 90% by recycling (Kucukvar et al., 2016).

5. C&D Waste Minimisation by Stages

Construction industry practitioners can use interventions to minimise waste in the supply chain, construction, repair and demolition stages. The supply chain stages include manufacturing, transportation and material handling remedies, while the construction stage remedies focus on optimising material consumption. Further, repair or refurbishment and demolition stage remedies are advised for processing surplus/waste to divert them from landfills. This section discusses C&D waste minimisation interventions practised at different project stages.

5.1 Supply Chain

The supply chain involves the extraction, manufacturing and transportation of building materials. It covers materials flowing from the quarry to a construction site. In New Zealand, construction industry practitioners can attempt to minimise waste at the manufacturing stage by rethinking the process (Callaghan Innovation, 2013). For example, by replacing traditional building insulation materials with sustainable materials. Callaghan Innovation has provided technical and financial support to material manufacturers making insulation products from hemp, a bio-based sustainable material (Callaghan Innovation, 2013). Further, carpets can be redesigned with biodegradable and recyclable fibres such as Aquafil (Luqmani et al., 2017). However, the use of such waste minimisation practices in manufacturing is limited in New Zealand and requires more attention from construction industry practitioners.

Supply Chain Management (SCM) effectively controls the materials flow and minimises waste. SCM provides equal responsibilities among stakeholders and efficient control over resource flow (Ahmed et al., 2002). Applying SCM reduced waste by 10 % for perfect order fulfilment (Papadopoulos et al., 2016) and 20% for overall value at risk as a Key Performance Indicator (Wibowo et al., 2017). Applying Green SCM in material procurement allows a smooth material flow from extraction to consumption (Beldek et al., 2016). Green SCM promotes a cradle-to-cradle approach, incorporating reverse logistics to minimise waste (London et al., 2013). Using SCM to minimise C&D waste is not a common practice in NZ. However, few validated case studies suggested that the practice of SCM for material procurement minimises waste and promotes environmental benefits (Samarasinghe, 2014).

Just in Time is also considered a valuable tool for controlling inventory and reducing waste (Vinodh et al., 2011). JIT eliminates lead time, mishandling of materials, and transportation damage to materials through timely deliveries (Vinodh et al., 2011). Further, waste-efficient procurement eliminates waste by efficiently selecting, ordering, delivering and storing the materials to avoid damage (Li et al., 2015). The four crucial features of efficient waste procurement are suppliers' commitment, low waste purchase management, timely delivery, and waste-efficient Bill of Quantities (Ajayi et al., 2017). In addition, waste-efficient procurement increases labour productivity by 30% and reduces waste disposal costs by 20 % (Liu and Lu, 2018).

Material management plan avoids double handling of the materials and protects materials from damage, ultimately reducing waste. It has been argued that the Material Management Plan that includes the material storage layout and is updated after completing each activity (e.g. wall framing, internal wall lining) maximises on-site space for material storage (Olanrewaju and Ogunmakinde, 2020). In addition, a Material Management Plan helps avoid risks involved in material transport, such as unprotected material falling in transit and leakage or debris on the materials (Liu et al., 2020).

Further, tools such as BIM, GIS and Blockchain minimise waste in the supply chain stage (Deng et al., 2019). BIM and GIS help to improve the visual monitoring of materials flow and avoid damages and delays (Irizarry et al., 2013). Integrating BIM and GIS is argued to be one of the most efficient tools for waste minimisation. However, the complexity and lack of advanced skills to use these tools remain challenging for construction industry practitioners (Deng et al., 2019).

Blockchain technology can also be used to improve the supply chain of green building materials to minimise waste at all stages of the supply chain: from extraction at a quarry, green material supplier selection, purchasing, material management, waste management and reverses logistics (Kouhizadeh and Sarkis, 2018). A successful theoretical attempt to use Blockchain technology using RFID tags in the supply chain of ready mixed concrete showed that real-time tracking optimises the process and minimises losses from delivery delays (Lanko et al., 2018). However, contractors have poor control over on-site activities due to constraints like cost and weather. Therefore, the application of Blockchain in the building material supply chain requires more research and development.

5.2 Construction

Various environmental assessment rating tools promote sustainability in construction. For instance, Passive House certification recognizes highly energy-efficient homes. In New Zealand, the widely used Homestar rating system reflects efforts to optimize resource consumption and minimize construction waste. Projects with a 6 Homestar requirement necessitate a site-specific waste management plan, aiding contractors in identifying and quantifying waste streams and determining their waste reduction approach (BRANZ, 2019).

Toolbox meetings, a common practice on construction sites, cover topics such as construction processes, methodologies, material management, waste, hazard control, and safety (SiteSafe, 2017). SiteSafe's environmental site management course, developed in partnership with Auckland Council, equips residential builders and subcontractors with knowledge on on-site waste management (SiteSafe, 2022).

Transparent waste reporting is crucial, highlighting the scope of the problem and instilling a sense of responsibility (UNEP, 2015). REBRI templates are another valuable tool for contractors to record waste data and promote waste reduction. Waste handling services like Junk Run provide comprehensive waste reports, detailing weight, volume, and disposal information for contractors seeking waste diversion credits (Junk Run, 2022).

Numerous city councils have published Waste Assessment reports at an industry-wide level to stimulate thinking on C&D waste reduction, aiming for zero waste by 2040 (Auckland Council, 2018). Construction contractors, if not mindful, can inadvertently harm the environment through improper waste disposal, missing out on potential social benefits of waste diversion (NZGBC, 2015).

Auckland Council has taken steps to promote waste minimization by establishing learning units to educate industry practitioners about waste's environmental impact and encouraging a shift in attitudes towards waste reduction (Auckland Council, 2018). Furthermore, Auckland Council's 2018 Waste Management and Minimisation Plan (WMMP) considered the social benefits of waste minimization, including public health and safety, community involvement, job creation, and fostering pride among Aucklanders. The Council's Action Plan for minimizing C&D waste also prioritized community engagement programs (Auckland Council, 2018).

5.3 Demolition and Deconstruction

The “D” in C&D standards for “demolition”. Demolition is, of course not the only approach and deconstruction is also a strategy, which, if done properly can assist waste minimisation as it can enable more reuse of materials and greater recycling.

5.3.1 Demolition

Demolition stage interventions mainly focus on reusing and recovery approaches of waste minimisation. Auckland Council observed a set of waste minimisation interventions (Auckland Council, 2018) as follows:

- Reuse concrete, timber, plastic, polystyrene, and ceiling tiles.
- Lime from gypsum board is extracted to use as a fertiliser for the agriculture industry.
- Crushed concrete to fill the base for the road.
- Use of plastic bottle waste to make roads.
- Plastic waste to replace (to some extent) sand and concrete.
- Manufacturing of bio-based plastic façade.

The Auckland construction industry has some examples of reusing building materials. For example, contractors use online resource-sharing applications such as Civil Share, Trash and Treasure Facebook pages and Trademe to reuse building materials (Auckland Council, 2019). The online resource-sharing platforms can make it easier to upcycle materials and generate interest in reclaimed C&D materials. For example, Civil Share is an Auckland-based free website app that diverted over 10,000 tonnes of waste from landfill within two years of its launch (Low et al., 2020).

A case study from the Whole House 'Reuse' project showed that remanufactured products, such as artwork from timber, have a potential secondary market in NZ (Zaman et al., 2018). Furthermore, 'saveBOARD', a Hamilton-based company, converts packaging waste into construction boards. The 'saveBOARD' construction boards are low carbon and environmentally sustainable, made from packaging waste such as used beverage cartons, soft plastics and coffee cups. In 2021, the company produced 400 boards daily and diverted 4,000 tonnes of waste from landfill (Sustainable Business Network, 2022).

The Rotorua District Council noted that crushed concrete has the largest secondary market in Auckland if it meets industry requirements and generates profit for the recycler. As a result, the Aggregate Quarry Association has developed a standard for recycled crushed concrete. Furthermore, New Zealand Transport Agency (NZTA) amended M/04 Standard for Basecourse Aggregate. As a result, it now has specifications developed for using recycled crushed concrete in the M/04 standard (Rotorua District Council, n.d.).

Recycling of C&D waste and margins on recycled products received adequate attention from NZ construction industry practitioners. As a result, in 2020, the NZ government invested NZD 124 million in recycling infrastructure to reduce waste. For example, Green Gorilla, a C&D waste recycler, received NZD 3.1 million to expand its innovative waste recycling facility (Beehive.govt.nz, 2020). Further, the NZ government identified the need for community recycling centres and provided NZD 1.1 million to Waste Revolution (a collaborative initiative between Junk Run and Kiwi Recycling) to create a resource recovery centre in Auckland (Parkar, 2022).

One of the largest housing providers, Kāinga Ora, is implementing a significant environmental strategy (Kāinga Ora, 2022). This organisation maintains approximately 69,000 homes and aims to build an additional 1000 each year. The strategy is ambitious including:

- support a transition to low-carbon construction,
- improve biodiversity and urban ngahere (forest) outcomes in our communities,
- protect and restore waterways surrounding our development areas,
- support low-carbon transport,
- reduce construction and demolition waste,
- ensure our homes and communities are resilient to future climate change impacts.

Specifically, in regards to demolition, this organisation prioritises relocation rather than demolition of existing building stock.

In developing countries, local NGOs partner with private recycling companies to share resources and divide waste responsibilities. It helps them to implement a take-back policy and create resale value for materials such as bricks, stones and concrete slabs (UNEP, 2019). In Brazil, the CI practitioners have established return depots for glass, plastic and paper across the country to improve waste collection and recycling (UNEP, 2018). Likewise, in New Zealand, companies such as EXPOL had collection bins across Auckland to collect Polystyrene waste (EXPOL, 2021). Further, similar initiatives were taken for other waste streams such as old carpets (Jacobsen Creative Surfaces), plasterboard (Green Gorilla), bathroom ware and timber (Waste Management Ltd) (Envirocon NZ, 2022).

5.3.2 Deconstruction

Deconstruction is a viable alternative to the demolition of buildings. Deconstruction is the reverse of construction as it requires removal of building materials in the reverse order they were installed in construction (BRANZ, n.d.b) and provides a greater opportunity to reuse, recycle and recover waste and increase landfill diversion than demolition. The Auckland Council has used deconstruction in some council-led projects. For example, in the Ranui community centre project, the Council managed to divert 99% of demolition waste from landfill and saved $33,000 (Auckland Council, 2018). Auckland Council has saved $800,000 through deconstruction through reusing and recycling timber, metals, concrete, glass, plasterboard, and door and window frames (Auckland Council, 2018).

Auckland Council has also supported the contractors involved in the infrastructure City Rail Link project to develop waste minimisation and resource recovery plans (Auckland Council, 2018). Deconstruction proved more effective than demolition and provided social, economic and environmental benefits. Therefore, it was considered an alternative to demolition in the Auckland region. By 2030, 7,000 homes will be demolished and replaced with 22,000 new homes in the region. It has been predicted that Auckland Council could save $25 million by deconstructing the 7,000 homes (Auckland Council, 2019).

6. C&D waste streams in residential projects in New Zealand

This section looks more specifically at C&D waste streams in residential projects in New Zealand. The waste streams analysed are timber, concrete, steel, plasterboard, packaging and plastic.

6.1 Timber

Timber is the most commonly used material in New Zealand construction's industry and is the highest contributor to New Zealand's C&D waste stream (Domingo and Batty, 2021).

Table 6: Estimated timber waste (tonnes) produced from C&D waste in residential projects (Nelson et al., 2022)

Timber	Building waste	Demolition waste	Total (tonnes)
	26,604	12,679	39,283

Managed forests are the primary source of timber for construction. Managed forests are where the trees are grown on farms or harvested from natural forests. New Zealand has significant managed forests: 10.1 million hectares, covering 38% of the land. Of that managed forest, 1.7 million hectares are productive, contributing 1.6% to the country's GDP (Ministry of Primary Industries-MPI, 2023). In 2021, locally sourced timber recorded 88.8 wt.% of total timber consumption in New Zealand (Nelson et al., 2022). Efficient management of existing forests and timber processing is expected to meet any increase in demand for timber in construction (Ramage et al., 2017).

While no data is available on the volume of timber waste generated from sourcing timber, the New Zealand government has issued timber and wood procurement policy to ensure legally sourced timber products (Ministry of Business Innovation and Employment-MBIE, 2023; Ministry of Primary Industries-MPI, 2023).

Another important factor is the need to prioritise sustainable and responsible forestry practices to minimise the environmental impact of timber sourcing (Corradini et al., 2019). Clearcutting and illegal logging are highly detrimental practices that exacerbate the problem resulting in soil erosion, loss of wildlife habitat, and a dearth of biodiversity (Korkiakoski et al., 2023, Rand et al., 2023). In addition, as New Zealand witnessed during Cyclone Gabrielle, forestry waste ("slash" and whole trees), caused considerable damage, including destroying bridges and other vital infrastructure (RadioNZ 2023; Rosenberg, 2023). Therefore, sustainable and responsible forestry practices are required to preserve natural resources and infrastructure. Sustainable forestry practices include selective logging and replanting, supporting certified sustainable timber products to ensure sourcing from legally and sustainably harvested forests (Cerullo and Edwards, 2019; Umunay et al., 2019; Komdeur and Ingenbleek, 2021).

After harvesting, the timber is cut into different sizes, processed and treated as necessary (Charis et al., 2019). Untreated timber can be chipped and used in landscaping (Low et al., 2020) or firewood (Manley & Evison, 2016).

Transporting timber to construction sites can cause timber waste for several reasons, including poor handling, damage during loading and unloading, and packaging (Poon et al., 2004; Li et al., 2013; Daoud et al., 2021). Suggested strategies to reduce timber waste during transportation include training labour on handling wood products adequately, using specialised packaging materials, and securely fastening wood products during transport.

Timber formwork is a contributor to C&D waste. However, as concrete is not as dominant a construction material in New Zealand as it is in other countries, the C&D from timber formwork will be lower than in other countries where it can make up 20% to 30% of the total amount (Hao et al., 2021). A timber waste ratio of 32.2 kg/m^2 is calculated for residential construction (Domingo and Batty, 2021). Some timber formwork is being recycled and used for particleboard (Manley & Evison, 2016). Prefabrication reduces C&D waste, especially in countries like China where timber is commonly used for formwork. It eases landfill pressure and contributes to environmental and social improvement by reducing waste from timber formwork, concrete structures, and structural steel framing (Tam and Hao, 2014; Hao et al., 2021).

In New Zealand, most timber used for construction is treated (Environmental Protection Agency, 2020). Radiata Pine is a unique type of timber used commercially in New Zealand and Australia, is easily treated, and its cell structure makes it the most treatable timber species in the world (Ramage et al., 2017). Timber treatment involves using chemicals to protect the wood from decay, insects, and other environmental factors (Hannah, 2023). As a result, wood preservatives can leach into the surrounding environment, with varying levels of susceptibility depending on the type of preservative used (Altaner, 2022). Proper handling and disposal of waste generated during timber treatment is critical to protecting the environment and human health. Therefore, companies that perform timber treatment must follow strict regulations and guidelines for managing and disposing of waste, including adequately labelling and storing hazardous waste, using containment systems to prevent soil and water contamination, and implementing practices to reduce waste generation. Additionally, using non-toxic and environmentally friendly timber treatment methods (Adhikari and Ozarska, 2018), such as natural oils and preservatives, can help reduce the amount of hazardous waste generated during the timber treatment process. There is no information available on the quantities and types of waste generated during the treatment of timber in New Zealand.

Treated timber waste is Auckland's largest source of recycled timber, primarily obtained from construction and demolition activities. Treated timber is commonly used in construction, mainly residential construction. Organic waste in the form of timber makes up a significant 12% of the total waste in New Zealand's landfills. The precise proportion of treated timber is yet to be determined, but it is expected to be substantial, given the widespread use of treated timber locally. Copper Chrome Arsenic (CCA) is the most commonly used wood preservative in New Zealand for treating timber. Although CCA has been phased out in many countries due to health and environmental concerns of handling and disposal, it is still promoted that it is environmentally friendly to be used and disposed of in New Zealand. (Hannah, 2023; University of Canterbury, 2023).

Treated timber has limited recycling and reusing options due to economic feasibility, environmental impacts, and no sustainable end-of-life option (Hannah, 2023). A further challenge is mixed timber in landfill limiting the diversion of untreated timber due to contamination. Some industry firms have partnered with waste operators to divert timber waste from landfills, aiming for a 70% diversion rate. Thus, reusing treated timber only delays addressing the environmental problem. Currently, the reuses of treated timber waste are limited, such use as an energy source at Golden Bay Cement (Green Gorilla, 2023), although burning of treated timber for energy has significant environmental issues (Rabajczyk et al., 2020) and must be carefully implemented. Or timber is disposed in landfills. Untreated timber can be chipped and used in landscaping (Low et al., 2020).

In Canterbury the only way to dispose of treated timber waste is by landfilling, which is costly and results in no reuse, recycling or energy recovery. There is a need to explore alternative options in New Zealand to turn treated timber waste into a resource by reusing, recycling or recovering energy from it (Environment Canterbury Regional Council, 2023).

Currently, reducing the amount of timber sent to landfills is the primary focus of the building and construction sector in New Zealand. Suggested strategies are to improve designs and plans, more efficient estimates for material quantity, offcuts reduction, and on-site sorting of materials. For buildings approaching the end of their life, suggested strategies include renovation, refurbishment, and refitting (Ministry for the Environment, 2023).

In addition to timber, various timber-based products such as fibre board, veneer, plywood, particle board, glulam, and laminated veneer lumber (LVL) are used in residential construction. The proportion of timber and timber-based products used in New Zealand is only known for the timber consumed in the country. This consistency in timber supply is expected to be due to larger forests, which take up to 60% (Nelson et al., 2022) of the forestry market and are managed with an aim to provide a consistent rate of return, leading to a steady rate of harvesting.

Various strategies are available to mitigate the waste generated during timber sourcing for construction.

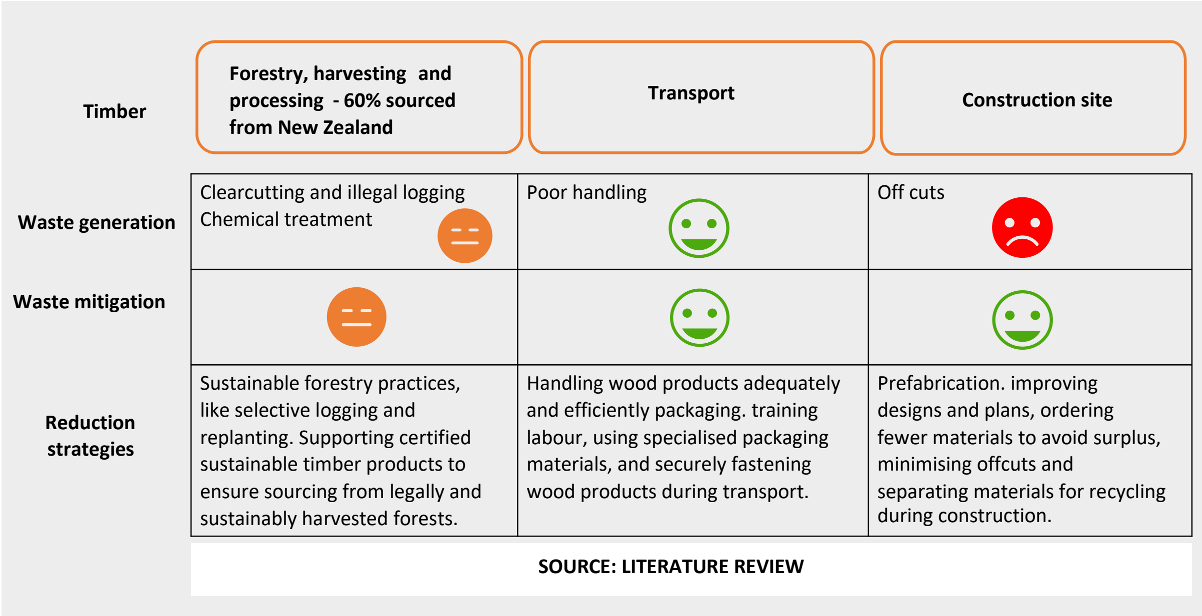

Figure 2: System mapping for Timber waste.

(The green face represents positive, orange is neutral and red poor)

6.2 Concrete

Concrete is a common part of C&D waste in New Zealand (Nelson et al., 2022; Low et al., 2020). Sources of concrete waste are varied and include surplus wet concrete from over-ordering or poor estimating (Helm, 2018). Concrete waste also includes concrete removed during demolition or renovation.

Concrete is estimated to take up to 7% of C&D waste in New Zealand (Build Magazine, 2013). Table 2 presents a recent estimation to concrete waste (tonnes) produced from construction and demolition work in New Zealand's residential projects (Nelson et al., 2022).

Table 7: Estimated concrete waste (tonnes) produced from C&D waste in residential projects (Nelson et al., 2022)

	Building waste	Demolition waste	Total
Concrete	71,268	78,164	149,432

As with timber, the effects on the environment are broader than generating physical waste. Concrete manufacturing produces significant amounts of CO2. Concrete manufacturing is estimated to contribute 8% of global CO2 emissions (Callaghan Innovation, 2022). In New Zealand, the production of ready-mixed concrete in 2021 amounted to approximately 4.5 million cubic metres, resulting in a large amount of cement and CO2 emissions (Nelson et al., 2022)). Recycled products perform similar to naturally resourced products (Atlas Concrete, 2023). Additionally, mining sand and coarse aggregate for concrete require a significant amount of fuel and energy consumption. Therefore, reducing emissions requires maximising the lifespan of concrete products by facilitating recycling and reusing as possible. Although some local demolition companies recycle concrete (mainly in the

Auckland region, such as Atlas, Quarry Auckland, and EnviroWaste), most concrete waste is disposed of in landfills. While these issues are significant, there are waste mitigation measures. Concrete New Zealand has released a roadmap to achieve net zero carbon by 2050 (Concrete New Zealand, 2023).

A study in New Zealand explored the feasibility of using recycled concrete aggregates (RCAs) as an alternative to natural aggregates (NAs) in producing concrete in ready-mixed concrete plants. The study intentionally produced RCAs and compared their properties with those of NAs. A matrix of mix types was developed to analyse the impact of using various recycled aggregate strengths to produce low, medium, and high-strength concrete. The study revealed that all strength grades of RCAs were suitable for low-strength concrete, but for medium and high-strength concrete, the RCA needed to have a source strength matching or exceeding that of the new concrete. The inclusion of fly ash did not significantly enhance compressive strengths. Field trials demonstrated that RCA concrete was indistinguishable from NA concrete. The study aims to foster confidence in using RCAs and establish standard specifications for the widespread adoption of RCA in New Zealand concrete production (Zhang and Ingham, 2010).

The international context of concrete reuse and recycling is focused on the rethinking and redesign of concrete products for efficient waste reduction. For example, in the US, Adopting technologies, such as 4D-BIM, can improve resource recovery and minimizing waste disposal in landfills (Guerra et al., 2019, Guerra et al., 2020). Furthermore, literature suggests that by incorporating biomass into cement-based materials, the production of ordinary Portland cement can be significantly reduced. Not only does this benefit the environment and human health, but it also allows for improved agricultural waste recycling. Additionally, this practice can create job opportunities and enhance the standard of living in agricultural communities (Ofori-Boadu et al., 2021).

Concrete waste can be reduced by controlling the mix proportion, using accurate measurement, and proper planning during the construction process. Additionally, using alternative materials for formwork like plastic or reusable formwork can also be a sustainable solution to reduce the waste.

Some research focused on recycled concrete's characteristics and mechanical properties to use it as a substitute for natural coarse aggregate in concrete. For instance, the characteristics for recycled concrete including: the compressive, tensile, and bending strengths are similar, and using construction debris as coarse grain is conceivable with minimal modifications to the material's properties. However, the high water absorption of these materials is the primary concern with these concretes. (Patra et al., 2022). Recent literature highlights the potential benefits of incorporating concrete waste materials into construction processes, promoting sustainability and resource efficiency (Liu et al., 2022; Gyurkó et al., 2019).

Prefabrication techniques could achieve waste reduction from concrete formwork can be decreased by 60% to 72% for prefabrication of straight walls and slabs (Cheng et al., 2022). However, this percentage could go as high as 90% if all of the building was prefabricated (Cheng et al., 2022). Prefabricated components produce less concrete waste than traditional methods. However, transportation and installation may damage some components. Therefore, the waste from damaged parts must be considered for effective waste reduction (Hao et al., 2021).

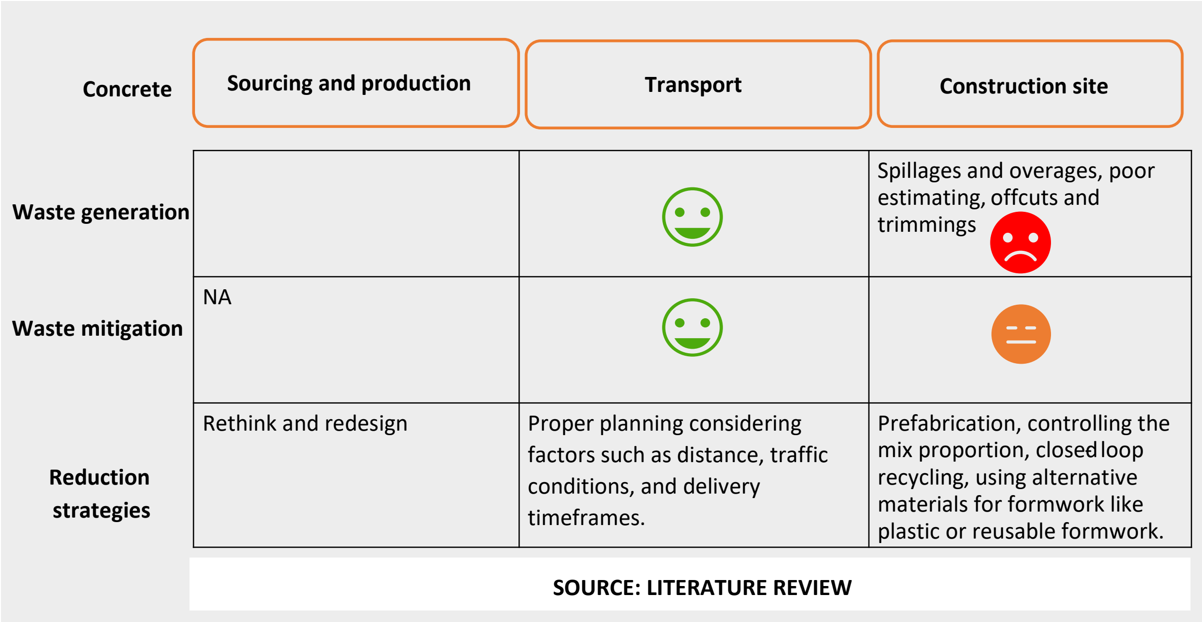

Figure 3: System mapping for Concrete waste

(The green face represents positive, orange is neutral and red poor)

6.3 Steel

Steel is recognised as having the highest recycling rate in the world, with a 85% recyclability rate in New Zealand and no loss of product quality (Kie Soo, V. et. al., 2021; Steel Construction NZ, 2023). Thus, unlike other building material such as timber, steel does not need to downcycled (Wu et al, 2022a). Moreover, steel scrap is an essential ingredient in producing new steel. New Zealand's average recycled steel content is around 5% from pre-consumer scrap (NZ Steel, 2023). Metal recycling is a thriving industry in New Zealand. The production of scrap steel is sourced from off-cuts created by manufacturers and steel contained in items that are no longer useful. Notwithstanding the ability to recycle steel, the energy intensive process of recycling steel in New Zealand creates significant CO2 emissions, through the burning of coal. The government's recent funding to New Zealand Steel for a partial conversion from coal to electricity, however, will almost halve those emissions with the installation of an Electric Arc Furnace (EAF) in 2026 (RadioNZ, 2023b). Indeed, in an assessment in 2020 of a newly built steel-framed house in New Zealand, the construction of such houses would not allow New Zealand to meet its commitments under the Paris Agreement (Wu et al., 2022a). However, this project did not consider the impact of the high percentage of reuse which is achievable with steel. This is despite steel having a high recovery rate in buildings, with recent research finding that approximately 90% of the steel in commercial construction is recycled (Ghose et al., 2017). Table 8 summarises the estimated steel waste (tonnes) produced from construction and demolition work in New Zealand's residential projects (Nelson et al., 2022).

Table 8: Estimated Steel waste (tonnes) produced from C&D waste in residential projects.

	Building waste	Demolition waste	Total
Steel	1,653	3,702	5,355

However, it is noted that steel offers various benefits, such as having low C&D waste rates, requiring low maintenance, having resilience, being easy to deconstruct, being reusable at the end of life, and being recycled infinitely.

Steel has valuable use in the expansion for off-site fabrication of building sections due to limited space on site (Mithraratne, 2015). Concerning the concept of a "circular economy," recycling materials like steel can be reintroduced into a new cycle, thereby decreasing the need for extracting raw materials and minimising the environmental consequences. A recent study (Roy et al., 2022) revealed that, in New Zealand, 231.4 m3 of steel waste was recycled from 2019-2021, of which 66% came from re-roofing/re-cladding and 34% came from manufacturing scraps. The study concludes that promoting a circular economy, particularly in New Zealand, recycling steel roofing and cladding can effectively mitigate harmful environmental impacts. However, it is crucial to acknowledge that recycling does not necessarily reduce all environmental impacts, which may entail trade-offs between environmental effects.

International practice, such as in Australia, has acknowledged that efficient reduction of steel waste requires the implementation of repetitive steel formwork and a strong emphasis on waste minimisation throughout the design and fabrication process, particularly when utilising offsite modularisation. Critical to this process is prioritising effective preliminary design and project development during the planning and design phase (Doust et al., 2021). In New Zealand HERA is developing a 'steel circularity passport' to better track material movement and reuse. In summary, reusing materials such as structural steel is particularly beneficial for reducing steel waste, because requires minimal processing and energy (Park and Tucker, 2017) .

In Malaysia, steel reinforcement bars are crucial elements in construction (Foo et al., 2013), but on-site waste occurs due to off-cuts by inexperienced workers. However, steel waste is a minor concern, accounting for only 4% of total waste and hold a high recycling value in the market.

There are other factors to consider with regard to steel outside of the construction process. Although outside of the scope of this report the manufacturing and demolition stages are a cause for concern due to type and amount of generated waste and emissions. Metals used in construction undergo various processing and manufacturing techniques, which results in high fuel consumption and carbon dioxide emissions, water and air pollution, waste production, and release of metal residues into the soil and water. In addition, these residues can harm aquatic organisms and contain highly toxic substances like mercury (Yahya et al., 2016). Demolition waste disposal involves separating reinforced steel from concrete, increasing energy consumption and machinery emissions during removal (Yahya et al., 2016). Information about the proportion of New Zealand steel used for residential and commercial buildings is not available (Nelson et al., 2022). Hence, more life cycle assessment is needed in New Zealand to assess waste production during manufacturing and demolition processes.

6.4 Plasterboard

Plasterboard, also known as drywall (Khechekhouche et al., 2022), is made from gypsum (a sulphate mineral) that is ground and mixed with water to form a paste for further processing (Başpınar and Kahraman, 2011). For example, plasterboard manufactured in New Zealand utilises natural gypsum, 100% recycled paper materials and other additives (White, 2023).The result is a robust and lightweight building material that is easy to cut and shape in different sizes and thicknesses, making it ideal for both residential and commercial construction. Plasterboards are used to construct walls and ceilings by attaching the plasterboard to a framework of studs or joists (Ariyanayagam et al., 2016). As discussed below plasterboard can be recycled and in recent years significant steps are being taken to recycle plasterboard (NZIQS, 2021). Indeed, plasterboard has high-value recycling applications, making it one of the few materials suitable for closed loop recycling (Jones and Gutiérrez, 2023).

In common with most materials used in construction, onsite deconstruction practices affect the amount of plasterboard that can be effectively recycled (Rodríguez Quijano et al., 2015). The deconstruction practices include, careful dismantling, site sorting, dry storage and transportation to recyclers. In addition, these practices can enable full recovery of all materials depending on the acceptance criteria from the recycler.

Plasterboard sourced from the demolition of buildings comprises recycled plasterboard extracted from walls, ceilings and other structures within the edifice. However not all recyclers will accept demolition material as it may be contaminated with lead based paint or asbestos texture finishing. The method of recycling plasterboard entails separating the gypsum from the paper and other debris, which can then be processed and utilised to produce new plasterboard products.

In addition, better planning and alternative construction methods can reduce plasterboard waste in New Zealand (Gálvez-Martos et al., 2018). For example, it is estimated that builders generate 12% of plasterboard waste as they cut plasterboard down to size for use in building project (Heeringa, 2023). Waste measured by WWB and others on residential new build sites has been in the 20-25% range or 4kg/m2 of floor area. Such waste can be reduced by manufacturing plaster boards in custom sizes, however, currently that option is available only for relatively large orders of 100 sheets or more (WasteMINZ, 2023).

In New Zealand, currently the recommendation still appears to be to recycle gypsum from offcuts, i.e. unpainted plasterboard, can be recovered and ground into a soil conditioner for use by farmers and others (Heeringa, 2023). Additionally, some construction companies have implemented closed-loop recycling systems to collect and recycle waste generated during construction. For example, Green Gorilla and Winstone Wallboards partnered in 2019 to provide plasterboard recycling services directly on-site within Auckland. As a result, approximately four million kilograms of plasterboard were recycled instead of being sent to landfills (White, 2023). For example, ground plasterboard off-cuts can be transformed into Green Gorilla gypsum, which has multiple uses such as fertiliser, compost, or cement additive (Ministry for the Environment-MfE, 2021; Low et al., 2020). In addition, Winstone Wallboards aims to include approximately 10% recycled gypsum in new plasterboard manufactured at its new Tauranga manufacturing plant that was commissioned in 2023. Plasterboard recycling services are available in Auckland, Waikato, Nelson, Christchurch, and Central Otago (White, 2023). And will soon be available in Tauranga in Winstone Wallboards' new plasterboard manufacturing and recycling plant (Vaughan, 2023).

For context, in Europe, about 600,000 tonnes of are recycled into new plasterboards in 2019, and this is considered to be insufficient (EuroGypsum, 2021). There, utilisation of up to 30% of recycled plaster in new plasterboards is recommended (EuroGypsum, 2015). More research is currently emerging on performance of such applications.

Table 9: Estimated plasterboard waste (tonnes) produced from C&D waste in residential projects.

	Building waste	Demolition waste	Total
Plasterboard	64,981	30,000	94,981

Recycled gypsum, obtained from waste plasterboard has been found to enhance soil performance, although a clay base needs to be broken down to allow for improved drainage. (Ahmed et al., 2011). Emerging international research claims recycling can be achieved by stabilising and strengthening the soil with recycled gypsum and solidification agents, including cement (Ahmed and Ugai, 2011). However, this has not been attempted in New Zealand and Le & Airey (2017) note that because of solubility concerns with gypsum, there is no assurance over its long term durability. Potential toxicity concerns in presence of biomatter in soil should also be considered for all in-ground applications of gypsum.

Another use of gypsum is following soil excavation, where it can be used for trench backfilling to prevent the trench from settling, shifting and eroding (Rahman and Ghataora, 2011). In a study conducted by Onishi et al. (2012), the performance of a recycled gypsum foundation for constructing single-family houses was evaluated. The recycled gypsum was obtained from waste gypsum boards generated from new or demolished buildings. The study's findings indicate that the gypsum foundation exhibited either equivalent or superior performance to existing foundation work methods. However, the above mentioned concerns of solubility of gypsum also apply here.

Bassanite can be produced from the gypsum in waste plasterboard, which in turn can be used to stabilise soil (Kamei et al., 2012 and Kamei et al., 2013). The use of bassanite in this way is a low-cost and efficient stabilising material in ground improvement projects (Ahmed, 2015). However, in an initiative in Japan for ground improvement projects, the bassanite released fluorine, which could exceed established limits and contaminate the soil (Kobayashi et al., 2015). Therefore, use of bassanite in soil is decreasing in popularity.

The potential to use gypsum in the manufacturing of new fire-isolating materials has been investigated with promising results (Leiva et al., 2010, Pérez-Moreno et al., 2013). Gypsum also has the potential to reduce the amount of Portland cement required in construction. 5-7% of natural gypsum is used in the manufacture of cement in NZ. One study in the UK found that 30% of cement could be replaced by gypsum without impacting strength and durability (Rodríguez-Orejón et al., 2014; Ganjian et al., 2015a; Ganjian et al., 2015b).

Onsite deconstruction practices can lead to cost savings and effective dismantling, sorting, and loading of materials (Rodríguez Quijano et al., 2015). In addition, these practices can enable full recovery of materials depending on the acceptance criteria from the recycler. Plasterboard sourced from the demolition of buildings comprises recycled plasterboard extracted from walls, ceilings and other structures within the edifice. The method of recycling plasterboard from demolition waste is similar to that of new plasterboard. The process entails separating the gypsum from the paper and other debris, which can then be processed and utilised to produce new plasterboard products.

Plasterboard	Sourcing and production	Transport	Construction site
Waste generation	NA	🙂	unused material, offcuts, and scraps of paper used in manufacturing ☹
Waste mitigation	Closed-loop recycling. Recycled plasterboard used in soil improvements 😑	NA	Landfilling and recycling 😑
Reduction strategies	Rethink and redesign	Accurate estimation and avoid over ordering.	Alternative construction methods. Recycling and reusing.
	SOURCE: LITERATURE REVIEW		

Figure 4: System mapping for Plasterboard waste.

(The green face represents positive, orange is neutral and red poor)

6.5 Packaging: Cellulose, paper and plastic

Nelson et al. (2022) found that packaging was a significant issue in New Zealand residential construction sites, with plastic the primary source of packaging waste. In Auckland alone, it is estimated that around 25,000 tonnes of plastic from C&D waste goes to landfill (Berry et al, 2022). Plastic waste is divided into two main categories, polyethylene (PE) and polyvinyl chloride (PVC), sourced from building protection, packaging, and building components. Plastic packaging contributes up to 42% of total C&D waste by volume in New Zealand, with a relatively constant mass across all construction phases (Berry et al., 2022). Professor Terri-Ann Berry has published extensively on redirection of construction site plastics.

Improper packaging contributes to unnecessary waste, increased costs, and environmental impacts. (Oko John and Emmanuel Itodo, 2013; Umar et al., 2018). Manufacturers can make slight design improve their packaging, which can reduce packing costs and associated logistics (Sierra and del RÃo Merino, 2017). However, it is essential to note that highly efficient packaging may have a more significant environmental impact across various metrics. As a result, manufacturers pursuing eco-friendly redesign strategies must approach the task thoughtfully, considering multiple variables beyond just reducing the packaging's weight. Eco-design integrates environmental factors throughout a product's life cycle. It requires manufacturer commitment and incorporates environmental criteria during the design phase without compromising other product properties.

The amount of cardboard waste generated can vary depending on the size and complexity of the construction project, as well as the materials used. Recycling and reusing cardboard waste from construction and demolition can be challenging, as it can be mixed with other materials, such as concrete, wood, and plastics (Hossain et al., 2017). Separating the cardboard from the other materials can take time and effort and in New Zealand, unlike other countries such as the UK, most construction waste is not sorted onsite (Hernandez et al., 2023. Additionally, the quality of the cardboard waste may not be as good as that of new cardboard, and it may only be suitable for some applications. Paper and cardboard waste is mainly obtained from packaging materials in constructing new buildings (Sormunen and Kärki, 2019). Therefore, the availability of material handling facilities and recycled markets influence best recycling packaging waste practices.

In addition, some countries like Germany practice reverse logistics and closed loop recycling practices to collect and recycle packaging and materials waste generated during the supply chain process (Bär and Schrems, 2021). The amount and type of packaging waste generated in the supply chain varies depending on the size and complexity of the construction project, as well as the materials used.

Hernandez et al., (2023) conducted a study in Auckland across four sites to quantify the plastic waste generated by commercial construction sites at different stages. The plastic waste was collected from three distinct stages of construction: demolition, exterior and weatherproofing, and services and cladding. The study revealed a cumulative total of 112kg of plastic waste. Polyethylene and polyvinyl chloride were the two primary types of plastic analysed, making up 77% and 31% of the total mass, respectively. The cause of plastic waste at the four locations varied and depended on the stage of construction. Nonetheless, it was evident that plastic packaging was not the sole source of concern, and it was necessary to examine the contribution of plastic building components and protective materials.

While there are available data for commercial construction, there is limited information about residential construction; however, smaller residential sites are expected to produce more waste, especially as smaller contractors find it harder to reuse materials or order in bulk. The responsibility for losing 20% of waste to landfills attributable to C&D waste linked to packaging falls on the supplier, necessitating increased accountability (Low et al., 2020).

Trends in packaging waste in New Zealand align with the global trend. For instance, in Malaysia, packaging waste (wrapping plastic and paper) was identified as the site's second most highly generated waste (Foo et al., 2013). Similar case in the UK as packaging waste is a significant source of C&D waste, any recorded information about material waste should include packaging waste (O'Reilly, 2012). In addition, key strategies to mitigate packaging waste through materials procurement include implementing a take-back scheme, using waste-efficient materials, and minimising packaging. Reusability of packaging materials can also significantly reduce waste output, as packaging waste makes up a substantial portion of C&D waste (Ajayi et al., 2017b).

Packaging	Product design	Storage and delivery	Construction site
Waste generation	NA		Once the materials and equipment reach the construction site, the cardboard and pallets are often discarded as waste.
Waste mitigation	NA	NA	
Reduction strategies	Rethink and Ecodesign	Improved handling practices, right size packaging, Just in time delivery.	Recycling. Onsite waste segregation to avoid contamination. Take back schemes.

SOURCE: LITERATURE REVIEW

Figure 5: System mapping for packaging waste

(The green face represents positive, orange is neutral and red poor)

7. Actions and conclusion

The main limitation that the research confronted time and time again was the reliance on manual techniques for quantifying construction waste. This means a lot of the data is necessarily approximate, and this will present challenges for measuring the effect of changes aimed at redirecting materials away from landfill. However, there are a number of short-term and long-term actions that are needed to transition the sector.

As discussed, it is noteworthy that data collection remains predominantly a manual process. This is increasingly problematics as it not only leading to inherently approximate measurements, but it also presents health and safety challenges. Additionally, this poses challenges in validating and quantifying changes in construction processes or practices. While current techniques have proved useful and provided useful data they are not sustainable. Currently there is a surge in novel combinations of machine learning, image recognition and artificial intelligence. The ability to identify features in images and video is a well-established. Research into methodologies for applying this is construction could be undertaken immediately.

Additionally, a distinct pattern emerged with the prevalence of waste mitigation efforts focused on the construction site itself compared to the relatively limited mitigation activities earlier in the supply chain. Materials on the construction site get mixed, rendering deconstruction for redirection and reuse complex. This is further complicated by the need to allocate space and logistics on a construction site for material surplus to be managed. This puts a lot of the financial and logistical responsibility for waste on the 'end-of-pipeline' contractor or sub-contractor. A systematic mapping of the supply chain would reveal waste stream redirection prior to its arrival on construction sites. A similar systematic mapping of potential markets for this material is also required. Simultaneously, investigating waste-minimizing design strategies is encouraged, as a reduction in waste generated directly addresses the underlying problem. This might include but is not limited to technology solutions; inclusion of waste management in professional accreditation; or specific tertiary courses that feed graduates into the building sector.

A more complex challenge pertains to behavioural aspects and the overall cost structure of construction. Expenses associated with handling and disposing of construction waste are factored into construction bids and contracts, ultimately passed on to project financiers. Gradual increases in waste management costs are likely to affect builders uniformly, thus not significantly advancing waste reduction objectives. The prevailing economic reaction to escalating costs in one aspect of production often involves cutting costs elsewhere. While this is a dominant cost paradigm worldwide, there is a growing acknowledgment of alternative frameworks, including indigenous knowledge systems that offer diverse perspectives. Embracing concepts from Mātauranga Māori could potentially cultivate innovative approaches to this challenge.

Finally, both material reuse centres, which focus on practical aspects of reusing materials and efficient aggregation, continue to heavily rely on labour-intensive and costly manual methods. To make significant progress in diverting materials from landfills, innovative systems and approaches must be developed that allow for scalability while reducing labour intensity and expenses. Furthermore, many individuals in the industry find it challenging to change behaviour in this regard. Ongoing reports in the media about recycled materials ending up in landfills can create doubts about the effectiveness of efforts to redirect materials for reuse, leading to significant resistance to behavioural change. Establishing a national system to verify the effectiveness of pathways for reuse and redirection would not only reduce the burden on individual companies but also instil greater confidence that these systems are indeed diverting waste away from landfills.

To conclude, C&D waste is recognised as a significant contributor to landfill, both internationally and in New Zealand. Despite the recognition of C&D waste and considerable attempts by governments, councils and other organisations, over many decades to reduce C&D waste at all stages of the supply chain, levels of waste remain stubbornly high. Many factors contribute to the continued problem of C&D waste, these include: poor design of materials, poor estimation of materials, lack of on-site sorting of waste, demolition rather than deconstruction, lack of recycling facilitates in New Zealand, limited and therefore low or unprofitable secondary markets and the low cost levy cost of materials going to landfill. Yet, there are pockets of good practice throughout New Zealand, which can be built upon.

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