Towards Circularity in Construction: Promoting the Uptake of Reprocessed Construction Materials

by

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This work is a heartfelt tribute to my beloved father, mother, and sister in recognition of the tremendous sacrifices they have made to help shape me into the person I have become today

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LIST OF ABBREVIATIONS

AEC	-	Architecture, Engineering, and Construction
BIM	-	Building Information Modelling
C&DW	-	Construction and Demolition Waste
CCA	-	Copper-Chrome-Arsenate
CP	-	Construction Professional
CPD	-	Continuing Professional Development
DW	-	Demolition Waste
EPA	-	Environment Protection Authority
ESD	-	Environmentally Sustainable Design
EU	-	European Union
FWPA	-	Forest and Wood Products Australia
GBCA	-	Green Building Council of Australia
GECA	-	Good Environmental Choice Australia
ISCA	-	Infrastructure Sustainability Council of Australia
ISO	-	International Organization for Standardisation
LEED	-	Leadership in Energy and Environmental Design
MRF	-	Material Recovery Facility
NABERS	-	National Australian Built Environment Rating System
NACOE	-	National Asset Centre of Excellence
NATA	-	National Association of Testing Authorities
RCAs	-	Recycled Concrete Aggregates
RCMs	-	Reprocessed Construction Materials
RFID	-	Radio Frequency Identification
RL	-	Reverse Logistics
RLSC	-	Reverse Logistics Supply Chain
UK	-	United Kingdom
US EPA	-	United States Environmental Protection Agency
WARRIP	-	Western Australian Road Research Innovation Program

ABSTRACT

Reverse logistics (RL) offers a viable solution to the challenges posed by the growing quantities of demolition waste (DW) and the high consumption of virgin resources within the construction industry. RL for DW encompasses a series of processes, including dismantling, reprocessing, secondary market operations and residue disposal. This collective sequence is termed the reverse logistics supply chain for demolition waste (RLSC for DW). Passing DW through these processes converts it into reprocessed construction materials (RCMs) that can be used in new construction applications. Previous studies have shown that the success of RLSCs for DW depends on the market uptake of RCMs. Overlooking this market aspect of the RL equation would render the process unsustainable in the long run. However, existing research highlights that the market uptake of RCMs is limited and that there is limited research focus on promoting the uptake of RCMs.

Occupying a central position within RLSCs for DW, waste processors play a crucial role by obtaining DW from demolition contractors and converting it into RCMs for sale and distribution to end users. Given that the success of waste recovery efforts of waste processors relies heavily on the market uptake of RCMs, previous studies have recognised that waste processors must structure DW recovery processes in a user-centric manner to meet the requirements of the end users of RCMs. This would enable waste processors to improve user satisfaction, subsequently promoting the uptake of RCMs. Despite the need for such a user-centric approach being acknowledged, a dearth of research exists in this area. Considering these knowledge gaps, the current study focused on exploring how the uptake of RCMs can be promoted among end users of RCMs and how waste processors can structure DW recovery processes in a user-centric manner to meet the requirements of the end users of RCMs.

The study was conducted in two phases. The first phase followed a qualitative survey approach to explore how the uptake of RCMs can be promoted. Thirty-one semi-structured interviews were conducted with construction professionals (CPs) from architectural, engineering, and contracting backgrounds, since they represent the key actors responsible for selecting materials for construction projects and thus act as end users of RCMs in RLSCs for DW. The data collected through the semi-structured interviews was analysed using the directed content analysis technique. Following a pro-environmental behaviour perspective, which recognised the uptake of RCMs as a pro-environmental behaviour to be undertaken by CPs, eighteen factors that could limit the uptake of RCMs were identified. Drawing on Attitude-Behaviour-Context (ABC) Theory, these limiting factors were broadly categorised as personal and contextual factors. The personal factors were further divided into attitudinal, personal capabilities, and habits/routines, while contextual factors were divided into client-related, organisation-related, cost-related, quality-related, availability-related, and regulatory environment-related. Further, twenty strategies for promoting the uptake of RCMs were identified, categorised into informational and structural strategies based on existing literature on pro-environmental behaviour. Informational strategies were further divided into information and education, modelling,

commitment, feedback, and credibility-building strategies, while structural strategies were divided into infrastructural and legislative/policy strategies. These strategies were also mapped against the stakeholders of the RLSC for DW responsible for implementing them.

Subsequently, the second phase of the study followed a case study approach to explore how waste processors could structure DW recovery processes in a user-centric manner to meet the requirements of end users, who, in this context, are CPs responsible for selecting materials for construction projects. Building upon the insights from the first phase, coupled with previous studies and reports from governmental and non-governmental bodies in Australia, it was discerned that the production of recycled concrete aggregates (RCAs) from DW is more developed and attuned to the requirements of CPs. Therefore, case studies were undertaken with three waste processing companies that produce RCAs from DW to understand the measures adopted by these companies when structuring their DW recovery processes to meet the requirements of CPs. This exploration unfolded across five areas: (1) effective marketing of RCMs, (2) enhancing the cost-competitiveness of RCMs, (3) assuring the quality of RCMs, (4) ensuring reliable supplies of RCMs, and (5) traceability of RCMs to previous uses. The selection of these areas was informed by the findings from the first phase on the strategies for promoting the uptake of RCMs. Document reviews and semi-structured interviews were used for data collection, while a cross-case analysis using the directed content analysis technique was used for data analysis. The case study findings led to the development of a best-practice framework for a user-centric DW recovery process that waste processors can use for structuring DW recovery processes in a user-centric manner to meet the requirements of CPs. The framework developed was also validated for its practical applicability through expert interviews.

The study contributes to knowledge by empirically investigating previously overlooked areas regarding how the uptake of RCMs can be promoted among CPs and how waste processors can structure DW recovery processes to meet the requirements of CPs. The study further makes notable contributions to theory by looking at the uptake of RCMs from the perspective of pro-environmental behaviour, a previously unexplored synthesis of two distinct domains. In practical terms, the study findings yield valuable insights for stakeholders of RLSCs for DW on the factors that limit the uptake of RCMs. Further, it provides these stakeholders with a comprehensive understanding of their specific roles in promoting the uptake of RCMs, thus ensuring the long-term sustainability of RLSCs for DW. Moreover, the framework developed specifically informs waste processors on how they can effectively structure their processes in a user-centric manner to meet the requirements of CPs. This framework serves as a valuable resource to enhance waste processors' capability to meet the expectations of CPs, ultimately facilitating the integration of RCMs into construction projects. While the current study is centred on the Australian context, future studies could extend these insights to the construction industries of other countries grappling with similar challenges related to waste management and resource limitations that hinder industry advancement.

Keywords: Demolition waste (DW), pro-environmental behaviour, reprocessed construction materials (RCMs), reverse logistics (RL), reverse logistics supply chains (RLSCs), user-centric demolition waste recovery

DECLARATION

This thesis presents work carried out by myself and does not incorporate without acknowledgment any material previously submitted for a degree or diploma in any university; to the best of my knowledge it does not contain any materials previously published or written by another person except where due reference is made in the text; and all substantive contributions by others to the work presented, including jointly authored publications, are clearly acknowledged.



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PUBLICATIONS

Journal publications

1. **Tennakoon, GA**, Rameezdeen, R & Chileshe, N 2022, 'Diverting demolition waste toward secondary markets through integrated reverse logistics supply chains: A systematic literature review', *Waste Management and Research*, vol. 40, no. 3, pp. 274-293. DOI: 10.1177/0734242X211021478
2. **Tennakoon, GA**, Rameezdeen, R & Chileshe, N 2022, 'Identifying factors affecting the low uptake of reprocessed construction materials: A systematic literature review', *Waste Management and Research*, vol. 41, no. 4, pp. 781-800. DOI: 10.1177/0734242X221135244
3. **Tennakoon, GA**, Rameezdeen, R & Chileshe, N 2023, 'Walking the talk towards sustainable consumption: interventions to promote the uptake of reprocessed construction materials', *Engineering, Construction and Architectural Management*, vol. ahead-of-print, no. ahead-of-print. DOI: 10.1108/ECAM-11-2022-1040
4. **Tennakoon, GA**, Rameezdeen, R & Chileshe, N 2023, 'Why not reprocessed: identifying factors limiting the uptake of reprocessed structural timber', *Built Environment Project and Asset Management*, vol. 13, no. 3, pp. 471-487. DOI: 10.1108/BEPAM-10-2022-0165

Conference publications

1. **Tennakoon, GA**, Rameezdeen, R & Chileshe, N 2022, 'Towards sustainable consumption: Enhancing the use of reprocessed construction materials within the Australian construction industry', in S Perera & M Hardie (eds), *The 45th Australasian Universities Building Education Association (AUBEA) Conference - Global Challenges in a Disrupted World: Smart, Sustainable and Resilient Approaches in the Built Environment*, Western Sydney University, Australia, pp. 446-455. (**Awarded the best paper award under the sustainability track*)

Other publications during the study period

1. Wijewansha, AS, **Tennakoon, GA**, Waidyasekara, KGAS & Ekanayake, BJ 2021, 'Implementation of circular economy principles during pre-construction stage: The case of Sri Lanka', *Built Environment Project and Asset Management*, vol. 11, no. 4, pp. 750-766.
2. Safshath, MIM, Waidyasekara, KGAS & **Tennakoon, GA** 2021, 'Application of nanotechnology and nanomaterials in the construction industry: The case of Sri Lanka', *2021 Moratuwa Engineering Research Conference (MERCon)*, University of Moratuwa, Sri Lanka, pp. 7-12.

CHAPTER ONE: INTRODUCTION

1.1 Background

Construction and demolition waste (C&DW) accounts for approximately 30-40% of the total solid waste generated globally (Huang et al. 2018; Li, CZ et al. 2020; Purchase et al. 2022; Tennakoon, Rameezdeen & Chileshe 2022b). This trend is similarly reflected within the Australian context, as evidenced by the National Waste Report 2020 (Pickin et al. 2020). The report indicated that 27 million tonnes of C&DW were generated in Australia during the 2018/19 fiscal year, representing 44% of core waste generation, making it the largest source of solid waste. C&DW includes two types of waste: construction waste generated during construction, repair, and renovation, and demolition waste (DW) generated during the dismantling of end-of-life structures (Chileshe, Jayasinghe & Rameezdeen 2019). Multiple studies have shown that the contribution of DW towards total C&DW is significantly higher than that of construction waste, with demolition being the fate of almost every building that has not been recognised as having a monumental or cultural significance (Behera et al. 2014; Chileshe, Jayasinghe & Rameezdeen 2019; Iacovidou & Purnell 2016; Srour, Chong & Zhang 2012; van den Berg, Voordijk & Adriaanse 2020). According to Iacovidou and Purnell (2016), 90% of C&DW comes from demolition, while only about 10% comes from new construction. Moreover, waste generated per unit of gross floor area in a demolition site is significantly higher – approximately 50 times greater – when compared to waste generated on a new construction site (Butera, Christensen & Astrup 2014). Evidence from Australia also supports this and indicates that the demolition of an average-sized house generates around 150-200 tonnes of waste, while only about 4 tonnes of waste is generated during the construction of a similar structure (Zero Waste SA n.d.). These findings highlight that it is prudent to prioritise the management of DW since it can significantly impact the minimisation of the overall volumes of C&DW.

Despite this, a significant percentage of DW generated is disposed of in landfills without any form of value recovery resulting in many detrimental effects on the environment,

economy, and society (Purchase et al. 2022; Wang, J et al. 2019). Even in Australia, approximately 40% of this waste stream continues to be disposed of in landfills, which is a considerably higher percentage than in some European countries that are at the forefront in waste recovery (e.g., Denmark – 95.9% recovery, UK – 95.9% recovery, Italy – 97.8% recovery) (European Environment Agency 2020; Pickin et al. 2020; Shooshtarian et al. 2020c).

While being an industry with substantial waste generation levels, construction also ranks high amongst the industries with the highest levels of natural resource consumption (Tennakoon, Rameezdeen & Chileshe 2022a). Globally, the construction industry consumes up to 50% of all raw materials extracted from nature (Norouzi et al. 2021; Verhagen et al. 2021). Continuous large-scale extraction of natural resources and high levels of energy consumption fuelled by the growing demand for construction can have negative consequences such as depletion and contamination of natural resources, loss of biodiversity, increased greenhouse gas emissions and adverse climate impacts (Bell 2018; Oyedele, Ajayi & Kadiri 2014). Due to increased urbanisation and the ever-growing population, it is also expected that the global material demand will triple from the 2016 levels before 2050 (Schandl et al. 2016). The outcomes from the recently concluded COP27 Summit revealed a noticeable disparity in the expansion rate in constructed floor area compared to the corresponding population growth rate, which implies a surge in construction activity that outpaces population growth (United Nations Environment Programme 2022). The Australian construction industry is also highly resource-intensive and is on a trajectory of increasing resource consumption. A recent study revealed that "*by 2060, the projected material demand for new buildings and replacing ageing buildings in Australia could range from 4.3 to 7.5 billion tonnes for alternative population growth scenarios*" (Soonsawad, Martinez & Schandl 2022, p. 180). As per the study, "*the upper range of the demand indicates a two-fold increase in building materials and associated environmental impacts*."

Humans are already consuming more resources beyond nature's regenerative ability, threatening the future supply of natural resources (Silva, de Brito & Dhir 2017). In fact, according to the One Planet Network, 1.5 Earths are required to sustain our current consumption levels (One Planet Network 2022). Therefore, it is imperative for the construction industry to look at avenues for minimising its high levels of primary resource consumption (Niu et al. 2021). From the Australian perspective, if the construction industry does not change how materials are produced and buildings are designed, the

country might not be able to achieve the goal of net-zero emissions by 2050 (Soonsawad, Martinez & Schandl 2022).

The studies cited above highlight two critical problems in the construction industry, both globally and in Australia. Firstly, the industry is grappling with ever-increasing volumes of DW. A notable proportion of this DW is landfilled without any value recovery due to its convenience and lower cost compared to other waste management options, such as recycling (Purchase et al. 2022; Wang, J et al. 2019). Secondly, the industry is accused of consuming large volumes of virgin materials amidst a looming scarcity of natural resources. A promising approach to address both these problems is to effectively recover and utilise DW as an alternative for virgin materials. This is where the concept of reverse logistics (RL) comes into play. Passing DW through a series of RL processes can convert it into reprocessed construction materials (RCMs) that can be used in new construction applications. This will avoid the unnecessary accumulation of DW in landfills and simultaneously relieve the ever-increasing demand for virgin materials from construction projects (Ramos & Martinho 2022). With the increasing understanding of RL and its application in other industries, the construction industry has also started to focus on adopting RL processes for converting DW into RCMs, thereby maximising resource utilisation.

Building upon the conceptualisation of RL by Rogers and Tibben-Lembke (2001), RL for DW can be interpreted as the movement of DW and related information from the point of dismantling end-of-life buildings to the point of new construction (Hosseini et al. 2015; Tennakoon, Rameezdeen & Chileshe 2022b). According to Jayasinghe, Rameezdeen and Chileshe (2022), this process involves four stages: dismantling, reprocessing, secondary market operations and residue disposal, and is collectively referred to as the reverse logistics supply chain for demolition waste (RLSC for DW). Dismantling is the process of demolishing or deconstructing an end-of-life building which results in the generation of DW and is undertaken by demolition contractors. This is followed by reprocessing where the DW generated during dismantling is recovered through different reprocessing techniques to be converted into RCMs. This process is undertaken by waste processors, who also then sends the RCMs to the secondary market to be used by end users in new construction applications, thereby creating a circular resource flow. Any residual waste that cannot be recovered is ultimately disposed of methodically. This provides a second life for waste materials that would otherwise be disposed of in landfills while minimising the demand for virgin resources.

Although RLSCs offer a systematic process for converting DW into valuable resources, the success of the process depends on the market uptake of RCMs (Yu et al. 2021). Therefore, overlooking the consumption or market aspect of the RL equation would render the process unsustainable in the long run. Multiple studies support this viewpoint, emphasising the direct influence of the market uptake of RCMs on the success of RLSCs for DW. Herein, Spoerri et al. (2009) and Yuan, Shen and Wang (2011) identified the presence of a functional market with sufficient demand for RCMs as a crucial prerequisite for the success of recycling schemes and maintaining high rates of DW recovery. Similarly, Srour, Chong and Zhang (2012) acknowledged the presence of markets for RCMs as one of the major factors underpinning the viability of DW recovery schemes. Furthermore, Silva, de Brito and Dhir (2017) and Ding, Nie and Wu (2022) asserted that as the mainstream applications of RCMs increase, there would be a corresponding increase in focus on recovering DW, thus underscoring the interdependence between the market uptake of RCMs and the growth of RLSCs for DW. These studies underline the importance of promoting the uptake of RCMs among end users to ensure the viability and success of RLSCs for DW.

Occupying a central position within RLSCs, waste processors play a crucial role by obtaining waste from waste generators and converting that waste into reprocessed materials, which are then sold and distributed to end users in the secondary market. Given that the success of waste recovery efforts relies heavily on the uptake of reprocessed materials by end users, previous studies on RL have emphasised the importance of waste processors structuring their processes in a user-centric manner to effectively meet end-user requirements (Carter, CR & Ellram 1998; Dowlatshahi 2000; Genchev 2009; Shokouhyar, Dehkhodaei & Amiri 2022). These studies indicate that adopting such a user-centric approach would improve user satisfaction and, consequently, help to promote the uptake of reprocessed materials. Following this line of thought, multiple studies have recognised that waste processors in RLSCs for DW must also follow a similar approach. For instance, Jayasinghe, Chileshe and Rameezdeen (2019) highlighted that upstream DW recovery processes must be oriented towards meeting the requirements of downstream markets for RCMs. Likewise, Liu et al. (2020) acknowledged that waste processors need to communicate more with end users of RCMs to understand their interests and subsequently develop new operating models that can be beneficial for achieving market success. Moreover, a recent study by Tennakoon, Rameezdeen and Chileshe (2022b) concluded that the success of DW recovery efforts depends directly upon the demand for RCMs and waste

processors must, therefore, act proactively to understand the requirements of end users and structure their processes accordingly. Adding to this, Tennakoon, Rameezdeen and Chileshe (2022a) noted that by structuring their processes to cater to the requirements of end users, waste processors could effectively promote the uptake of RCMs.

1.2 Problem statement

The background emphasised that the viability and success of RLSCs for DW rely heavily on the market uptake of RCMs. However, extant literature has shown that the market uptake of RCMs is, in fact, limited in most countries, including Australia, which has hindered the effectiveness of RLSCs for DW. As highlighted by Knoeri, Binder and Althaus (2011), most stakeholders in the construction industry are naturally conservative and prefer virgin materials over RCMs. This viewpoint was supported by Oyedele, Ajayi and Kadiri (2014), where the authors found that RCMs are not considered as viable alternatives for virgin materials in the UK construction industry. Based on a study in the Netherlands, Schut, Crielaard and Mesman (2015) reported that despite around 95% of the waste from the construction industry being recovered, only a meagre percentage (3-4%) is used in high-grade applications, while the rest is used for low-grade applications or in some cases is even disposed of without further use. Following a survey of the Chinese construction industry, Jin et al. (2017) concluded that RCMs are not readily accepted by industry practitioners in China. Likewise, the situation in Australia mirrors these findings, and as highlighted by Chileshe et al. (2015), the lack of demand for RCMs has been detrimental to the success of RL within the Australian construction industry. Similarly, a more recent study by Shooshtarian et al. (2020b) concluded that despite ongoing market development efforts, the performance of secondary markets for RCMs in Australia has been far from perfect. These studies collectively indicate a lack of demand for RCMs and a corresponding need for further studies aimed at promoting the uptake of RCMs among end users.

However, there is a limited focus in existing research on promoting the uptake of RCMs, especially in the Australian context (Shooshtarian et al. 2022a; Shooshtarian et al. 2020b; Tennakoon, Rameezdeen & Chileshe 2023). In light of this background, there is an increasing necessity for further research aimed at promoting the uptake of RCMs. Herein, the key focus should be on promoting the uptake of RCMs among Architects, Engineers, and Builders (collectively referred to as construction professionals (CPs) for the purposes of this study), who are the key actors responsible for selecting materials for construction

projects and thus act as end users in RLSCs for DW (explained in Section 2.8.2.2). Furthermore, previous studies suggest that promoting the uptake of RCMs can be viewed from a pro-environmental behaviour perspective, where the uptake of RCMs could be considered a pro-environmental behaviour to be embraced by CPs involved in material selection for construction projects (explained in Section 2.8).

Moreover, as highlighted in the background, the success of the waste recovery efforts of waste processors in RLSCs for DW relies heavily on the market uptake of RCMs. Therefore, waste processors must structure DW recovery processes in a user-centric manner to effectively meet the requirements of the end users of RCMs, who, in this context, are the CPs responsible for selecting materials for construction projects (Jayasinghe, Chileshe & Rameezdeen 2019; Liu et al. 2020; Tennakoon, Rameezdeen & Chileshe 2022b). This would enable waste processors to improve user satisfaction, which in turn would promote the uptake of RCMs. Despite the need for such a user-centric approach being recognised, recent studies revealed a dearth of research in this area (Jayasinghe, Rameezdeen & Chileshe 2019; Tennakoon, Rameezdeen & Chileshe 2022b, 2022a). Therefore, there is an imminent need for further research to understand how waste processors can effectively structure DW recovery processes in a user-centric manner to meet the requirements of CPs.

Based on the discussion above, two key knowledge gaps were identified as follows, which were addressed through the current study:

> Firstly, there exists a lack of research on promoting the uptake of reprocessed construction materials among construction professionals.
>
> Secondly, there exists a lack of research on how waste processors can structure demolition waste recovery processes in a user-centric manner to meet the requirements of construction professionals.

These knowledge gaps are elaborated in further detail in Chapter 2 (refer to Section 2.10). Based on these knowledge gaps, two research questions were developed for this study as follows:

> **Research Question 1 (RQ1)**: How can the uptake of reprocessed construction materials be promoted among construction professionals?

Research Question 2 (RQ2): How can waste processors structure demolition waste recovery processes in a user-centric manner to meet the requirements of construction professionals?

1.3 Aim

Based on the knowledge gaps and research questions identified, the current study attempts to investigate the perspectives of CPs on the uptake of RCMs and, drawing upon that, explore how waste processors can effectively structure DW recovery processes in a user-centric manner to meet the requirements of CPs. Therefore, the aim of this study was set as:

To investigate the perspectives of construction professionals on the uptake of reprocessed construction materials to structure demolition waste recovery processes in a user-centric manner to meet their requirements.

1.4 Objectives

Based on the research questions, four objectives were developed for the study as follows. The first and second objectives relate to RQ1, and the third and fourth objectives relate to RQ2.

Objective 1: To identify potential factors that limit the uptake of reprocessed construction materials among construction professionals through a qualitative survey

Objective 2: To explore potential strategies for promoting the uptake of reprocessed construction materials among construction professionals through a qualitative survey

Objective 3: To suggest measures that can be taken by waste processors for structuring demolition waste recovery processes in a user-centric manner to meet the requirements of construction professionals through case studies

Objective 4: To develop a best-practice framework for a user-centric demolition waste recovery process and validate it through expert interviews

Figure 1.1 maps the objectives with the knowledge gaps and research questions.

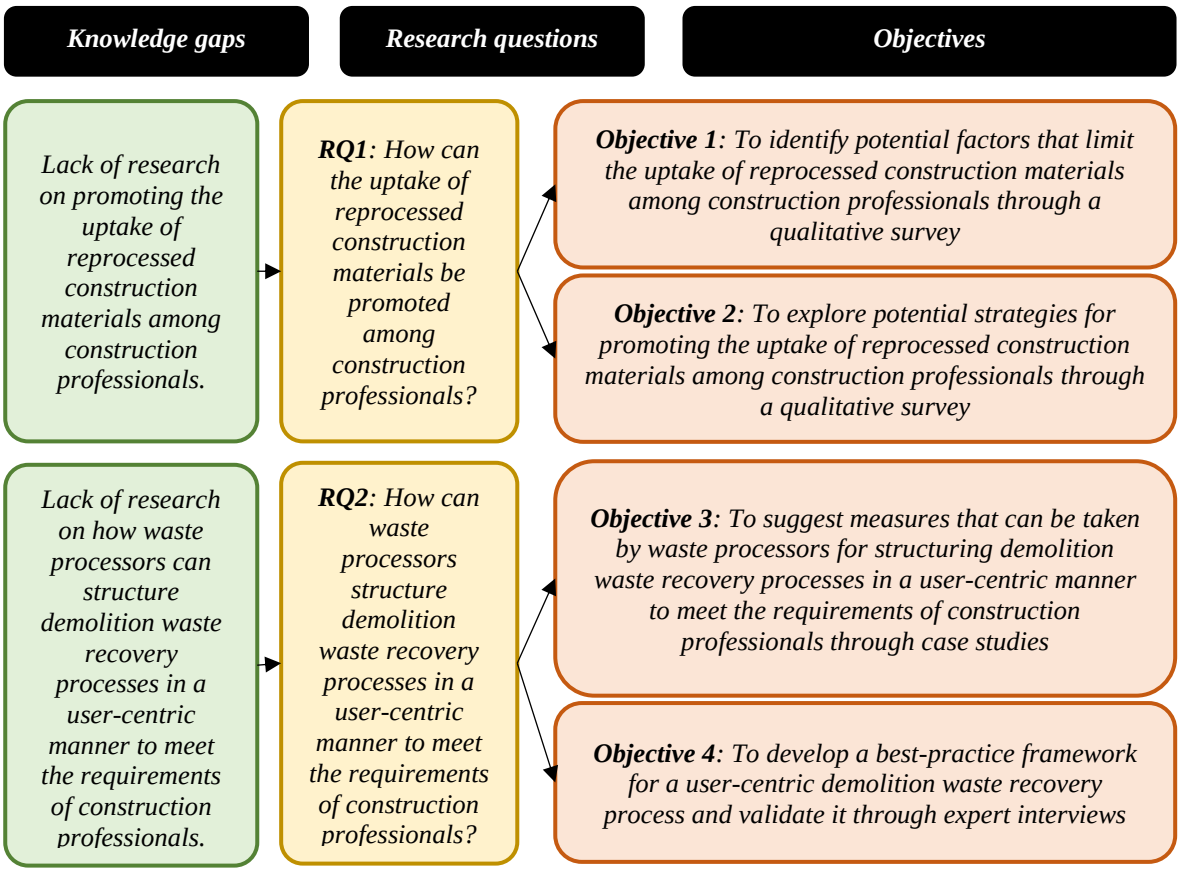


Figure 1.1: Mapping objectives with knowledge gaps and research questions

1.5 Overview of the research methodology

Based on the research questions posed, this study leaned more towards the philosophical position of interpretivism. Therefore, in line with the philosophical position of interpretivism, qualitative surveys and case studies were selected as suitable research approaches to address the specific research questions. This study comprised two phases. The first phase of the research followed a qualitative survey approach to address the first research question: "How can the uptake of RCMs be promoted among CPs?" In this phase, semi-structured interviews were conducted with thirty-one CPs from architectural, engineering, and contracting backgrounds with prior experience in using RCMs. The focus of these interviews was to identify potential factors that limit the uptake of RCMs among CPs and to explore potential strategies for promoting the uptake of such materials, consistent with the first and second objectives of the study. The data collected from these semi-structured interviews were analysed using the directed content analysis technique.

The second phase of the research adopted a case study approach to address the second research question: "How can waste processors structure DW recovery processes in a user-centric manner to meet the requirements of CPs?" Within this phase, case studies were

undertaken with three waste processing companies that produce recycled concrete aggregates (RCAs) from DW, representing a current industry best practice in DW recovery in Australia (explained in detail in Section 5.3). Data collection was carried out using document reviews (company documents, company website, and social media profiles (i.e., LinkedIn and YouTube)), and this data was verified using semi-structured interviews while also gathering additional data. A cross-case analysis was carried out to analyse the data, following the directed content analysis technique. Measures that can be used by waste processors for structuring DW recovery processes to meet the requirements of CPs were identified through the case studies. These identified measures were subsequently developed into a best-practice framework for a user-centric DW recovery process, consistent with the third and fourth objectives of the study. The framework developed was then validated using expert interviews to evaluate its practical applicability.

1.6 Scope of the study

The current study was limited to the Australian context, considering the resources available for undertaking the study and the possibility of accessing the required expertise and other relevant data for conducting the study. The focus of the study was also limited to analysing the RLSCs for DW and the RCMs derived from DW. This is because, as explained under the background, DW constitutes a substantial proportion of all waste generated in the construction industry, which was also found to be true in the Australian context. Therefore, it was recognised that it is more prudent to prioritise the management of DW since it can significantly contribute to reducing the overall volumes of C&DW.

For the first phase of the study, which involved a qualitative survey, only CPs from architectural, engineering, and contracting backgrounds were selected since these professionals were identified as the key actors responsible for material selection in construction projects. As part of the first phase, the current study identified a multitude of strategies that could be adopted to promote the uptake of RCMs among CPs. However, according to the approach for promoting pro-environmental behaviours adopted for the study (explained in Section 2.8.2), these strategies should be applied and evaluated for their effectiveness. Regrettably, this could not be done through the current study since it often requires experimental research designs, which are costly and time-consuming to execute and were therefore not feasible within the scope, funding, and timing constraints of the study.

Furthermore, during the second phase of the study, which involved undertaking case studies with waste processing companies, case studies were undertaken with companies involved in producing RCAs from DW. This selection was driven by insights gained during the first phase of the study and multiple documentary resources from the Australian construction industry, which collectively established that producing RCAs from DW represents a current industry best practice in DW recovery within the Australian context (explained in Section 5.3).

1.7 Significance of the study

While prior research has acknowledged that the uptake of RCMs remains limited in many countries, including Australia, there exists a gap in research regarding promoting the uptake of such materials. The current study bridged this gap by empirically identifying the limiting factors and strategies for promoting the uptake of RCMs from the perspective of CPs, who are the key actors responsible for material selection in construction projects. Notably, the study looked at the uptake of RCMs from a theoretical perspective of pro-environmental behaviour, a previously unexplored synthesis of two distinct domains. The study demonstrated that such theoretical perspectives can be used to gain insights into the uptake of RCMs among CPs, thereby extending the scope of these theoretical perspectives into the construction domain. Furthermore, the study mapped the strategies for promoting the uptake of RCMs against the stakeholders of the RLSC for DW, thereby offering implications for the practice of these different stakeholder groups regarding their role in promoting the uptake of RCMs.

Moreover, prior research has emphasised the importance of waste processors structuring DW recovery processes in a user-centric manner to meet the requirements of the end users of RCMs. Despite the need for such a user-centric approach being acknowledged, previous studies have failed to explore this aspect in depth. The current study addressed this gap by undertaking an in-depth empirical exploration into the measures that can be taken by waste processors for structuring DW recovery processes in a user-centric manner to meet the requirements of CPs, who were recognised as the key end users of RCMs. This was achieved through in-depth case studies with waste processing companies involved in producing RCAs from DW, which was recognised as an industry best practice. The best practice framework for a user-centric DW recovery process developed based on these findings offers practical implications for waste processors by outlining actionable measures that waste processors could take in structuring their processes to meet the requirements of

CPs. Notably, the current study is among the first to introduce the concept of user-centricity to the domain of RLSCs for DW, thus integrating two separate areas that had not been looked at together previously.

1.8 Structure of the thesis

As shown in Figure 1.2, the thesis consists of seven chapters. **Chapter 1** presents the research background, problem statement and the aim and objectives. This is followed by an overview of the research methodology, scope of the research, significance of the study and the structure of the thesis. **Chapter 2** provides a literature review on RLSCs for DW, the significance of promoting the uptake of RCMs, the current low uptake of RCMs, and an approach for promoting the uptake of RCMs from a pro-environmental behaviour perspective. Further, it discusses user-centric RL and user-centricity in RLSCs for DW and highlights the knowledge gaps addressed through the study. **Chapter 3** presents the research methodology adopted for this study and includes a discussion regarding the philosophical position of the study, the research approaches followed, and the research techniques used for data collection and analysis. Aspects related to ensuring the trustworthiness of research findings and ethical considerations are also discussed in this chapter. **Chapter 4** presents the findings from the first phase of the study on factors limiting the uptake of RCMs among CPs and potential strategies for promoting the uptake of such materials. **Chapter 5** presents the findings from the second phase of the study on measures that can be taken by waste processors to structure DW recovery processes in a user-centric manner to meet the requirements of CPs. The development and validation of a best-practice framework for a user-centric DW recovery process are also explained in this chapter. **Chapter 6** discusses the findings from the two phases of the study by comparing them with extant literature. **Chapter 7** outlines the conclusions of the study and presents a summary of research findings, contributions to knowledge, and practical implications, along with limitations and recommendations for future research.

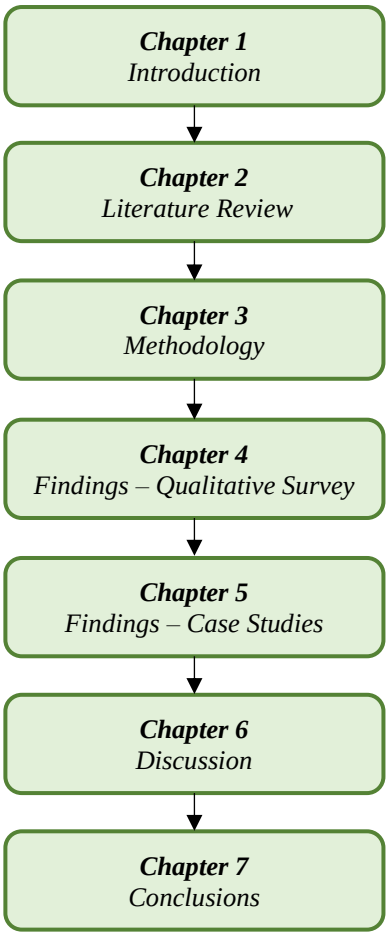


Figure 1.2: Structure of the thesis

1.9 Chapter summary

This chapter provided an introduction to this study, highlighting the background, problem statement, aim and objectives, and an overview of the research methodology. Further, the chapter explained the scope of the study, and its significance and presented the structure of the thesis. The next chapter provides an extensive literature review of the key concepts related to the area of study.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

Chapter 1 provided an introduction to the current study covering the problem statement, aim and objectives, overview of the research methodology and scope and significance of the study. This chapter presents an extensive literature review of the key concepts related to the area of study. According to Snyder (2019, p. 333), '*Building your research on and relating it to existing knowledge is the building block of all academic research activities, regardless of discipline*'. Based on this notion, the research process must commence with an extensive literature review to provide a comprehensive background of the research topic and establish a solid foundation upon which new research can be built. A thorough literature review enables a researcher to understand prior research undertaken within a specific domain, thereby identifying potential research gaps and defining research questions and strategies to be used (Grant & Booth 2009; Kahkonen 2011). Accordingly, a comprehensive literature review was undertaken as part of the research, which was continuously developed as the research evolved and progressed. The review enabled the researcher to understand the research area in-depth, uncover knowledge gaps, and identify similar studies already carried out in related domains. Journal articles, conference papers, books, industry reports and websites formed the primary literature sources for the review. The chapter introduces the concepts of reverse logistics (RL) and reverse logistics supply chains for demolition waste (RLSCs for DW), highlights the significance of the market uptake of reprocessed construction materials (RCMs) in ensuring the success of RLSCs for DW and the current low uptake of RCMs. Further, the chapter presents literature on pro-environmental behaviour and user-centric RL in relation to promoting the uptake of RCMs and concludes with the identification of knowledge gaps.

2.2 Introduction to reverse logistics

Traditionally, organisations have consistently focused on managing forward supply chains, which involves the process of moving materials from the point of origin to the point of consumption (Agrawal, Singh & Murtaza 2015). Organisations were not willing to take

responsibility for products that had reached their end-of-life. However, with a growing emphasis on concepts such as sustainable development, organisations started to realise the importance of managing the end-of-life impacts of their products and reducing their environmental footprint in parallel with maximising economic gains (Nasir et al. 2017). Driven by this realisation and the ever-increasing volumes of waste generated, organisations began to take a more proactive approach towards managing the end-of-life impacts of their products. Opportunities for minimising waste generation were considered, while options for managing unavoidable waste through returns management methods such as reuse, recycling, incineration, and energy recovery were explored (Agrawal, Singh & Murtaza 2015; Saeed, Hassan & Mujeebu 2009). As the discussion around managing end-of-life impacts grew, the concept of RL emerged.

Waste refers to resources that have lost their value or function or have not been used correctly and could still be made use of through reprocessing (Reike, Vermeulen & Witjes 2018). RL is an approach for reprocessing such resources classified as waste and enables value recapture from those resources. RL originated in the manufacturing industry to recover industrial and solid waste generated during manufacturing operations and determine alternative uses for these waste streams (Jayasinghe, Rameezdeen & Chileshe 2019). Simply put, RL involves moving used resources from consumption points to designated points of value recapture (Rogers & Tibben-Lembke 2001). These reverse supply chains complement forward supply chains to generate truly circular supply chains that characterise modern-day supply chain management systems which minimise waste sent to landfills (Govindan et al. 2012; Hosseini et al. 2014; Jayasinghe, Rameezdeen & Chileshe 2019).

2.2.1 Definitions of reverse logistics

With RL as a concept gaining ground in both research and practice, different definitions for RL have been presented, primarily from a manufacturing industry perspective. A seminal definition for RL is the one suggested by Rogers and Tibben-Lembke (1999):

> The process of planning, implementing, and controlling the efficient, cost-effective flow of materials, in-process inventory, finished goods and related information from the point of consumption to the point of origin, for the purpose of recapturing value or proper disposal (Rogers & Tibben-Lembke 1999, p. 2).

Subsequently, looking at RL from a supply chain perspective as a series of inter-related processes, Dowlatshahi (2005) defined a RL system as a supply chain that is designed to manage the flow of materials destined for reuse, remanufacturing, recycling, or disposal,

which is capable of effectively utilising resources that were previously disregarded. A similar definition was presented by Leite (cited in Nunes, Mahler & Valle 2009, p. 3717), where the author defined a reverse supply chain as:

> The stages and means through which the goods produced, or parts of them, return to the productive cycle, reacquiring value in secondary markets by reuse or the recycling of their constituent materials. If the return of these materials to the business cycle is not economically viable, there are options for final disposal, such as landfills and waste dumps.

Following these different definitions, this study considered RL as a chain of processes designed to maximise resource utilisation and capture the highest possible value from resources that would otherwise be disposed of without any value recovery. Where value recapture is not viable, RL ensures that such materials are disposed of systematically. Such a chain of processes was referred to as a reverse logistics supply chain (RLSC) in this study.

2.2.2 Reverse logistics in different industries

Studies have shown that adopting RL practices can provide both direct and indirect benefits. Direct benefits include a reduction in resource investment levels, a decrease in costs of storage, distribution, disposal and procurement of new materials, the creation of new employment opportunities and income generation, a reduction of landfilled waste and improved environmental protection (Govindan & Bouzon 2018; Guarnieri, e Silva & Levino 2016; Oliveira Neto & Correia 2019; Wilson & Goffnett 2022; Zhang, F & He 2022). Indirect benefits of RL can include an improved green image of organisations, increased customer satisfaction, enhanced customer and supplier relationships and anticipation of future legislation (Schultmann & Sunke 2007; Wilson & Goffnett 2022; Zhang, F & He 2022). Many industries have adopted RL practices driven by these benefits, including automobile manufacturing, electrical and electronic appliances, apparel, medicine, packaging and construction. Table 2.1 presents a summary of studies on the adoption of RL practices in different industries.

Table 2.1: Summary of studies on the adoption of reverse logistics practices in different industries (organised based on year of publication)

Reference	Industry	Key findings
Dowlatshahi (2005)	Automobile electronic components and medical manufacturing	Following a case study approach, the study provided a practical framework for designing and implementing remanufacturing/recycling operations in RL.

Reference	Industry	Key findings
Hung Lau and Wang (2009)	Electronics	Using the Chinese electronics industry as a case study, this study found that the drivers of RL vary from company to company, while barriers to RL are common and mainly external. A set of main barriers were also identified, including the lack of enforceable regulations, lack of economic support and preferential tax policies, low public awareness, and under-developed recycling technologies.
Geyer and Doctori Blass (2010)	Cell phones	The study undertook a detailed economic analysis of cell phone collection, reuse, and recycling and identified cell phone reuse as the most profitable disposition option that drives end-of-use handset collection in the USA and Europe.
Abraham (2011)	Apparel	The study mapped RL systems in the Indian apparel aftermarkets from the point of procurement of used clothing until its resale in aftermarkets. Study findings identified that stakeholder collaboration in RLSCs can increase market knowledge, improve business predictability, and provide better margins.
Chan, Chan and Jain (2012)	Automobile	The study developed a framework for RL in the automobile industry based on an investigation of RL drivers and key automobile components suitable for reuse or remanufacturing.
Guarnieri, e Silva and Levino (2016)	Electronics	The study structured the problem of electronic waste RL using the Strategic Options Development Analysis (SODA) methodology and identified the decision elements for implementing electronic waste RL as required by the Brazilian National Policy of Solid Waste.
de Oliveira, Luna and Campos (2019)	Expanded polystyrene packaging	The study mapped the forward and reverse supply chains for expanded polystyrene, identified the stakeholders in the reverse channel and the relevant logistics activities, reviewed the legislation on reverse supply chains and presented the barriers to implementing expanded polystyrene reverse chains in the Brazilian context.
Ribeiro et al. (2021)	Medicine	The study ranked RL best practices and the main difficulties in performing medicine reverse logistics within the Brazilian hospital sector.
Jayasinghe, Rameezdeen and Chileshe (2022)	Construction	The study identified risks in RLSCs for DW and assessed the inter-dependencies among these risks to improve quality-related operational performance in RLSCs for DW.
Wijewickrama et al. (2022a)	Construction	The study identified uncertainties in RLSCs for DW and information processing mechanisms to overcome such uncertainties. By combining these two elements, an information-processing management framework was developed to overcome uncertainties in RLSCs for DW.

2.3 Reverse logistics for managing demolition waste

Waste management is a crucial area of focus in improving the performance of the construction industry under economic, quality, and sustainability aspects (Bao et al. 2019; Udawatta et al. 2018; Zandee et al. 2022). Improper waste management increases the financial burden on clients, erodes the competitive advantage for contractors, decreases the quality and efficiency of construction processes and threatens the resilience of the natural environment. Therefore, exploring appropriate waste management options is imperative to minimise the substantial volumes of DW landfilled without any form of value recovery. This was further emphasised by Jayasinghe, Rameezdeen and Chileshe (2019), the authors advocated the use of sustainable post-end-of-life building operations for managing DW aligned with the triple bottom line criteria of sustainability. With the substantial increase in the volumes of DW generated, the environmental costs of landfilling and the depletion of virgin material resources, the construction industry should tap into the potential for generating RCMs from DW (Bao et al. 2019; Tennakoon, Rameezdeen & Chileshe 2022b). Herein, RLSCs can convert DW into value-added resources, which can be used in new construction applications.

RLSCs are designed to maximise resource utilisation and capture the highest possible value from resources that are otherwise destined for landfills. Consequently, a similar approach can be adopted for regenerating DW into RCMs that can be traded through secondary markets and diverted back into the construction industry without merely being disposed of as waste (Jayasinghe, Rameezdeen & Chileshe 2019, 2022). It will also ensure that any residual waste that is not recovered is disposed of systematically, thereby minimising any adverse effects on the environment. In this study, such a RLSC for managing DW was referred to as a reverse logistics supply chain for demolition waste (RLSC for DW).

Adopting RL for managing DW can provide many benefits, such as reduced pollution and toxicity in dismantling existing structures, increased longevity of construction materials, improved waste recovery and reduction of landfilled waste, lower dependency on virgin materials, increased economic activity through waste recovery operations, and reduced adverse environmental impacts (Chileshe, Jayasinghe & Rameezdeen 2019; Correia et al. 2021), thus making it an attractive proposition for the construction industry. With this realisation, several recent studies have been conducted on areas such as identifying drivers, critical success factors, barriers, and remedial actions for adopting RL in construction, mapping process risks and evaluating information management for improving process

quality in RLSCs for DW (Chileshe, Rameezdeen & Hosseini 2016; Correia et al. 2021; Jayasinghe, Rameezdeen & Chileshe 2022; Pushpamali et al. 2021; Wijewickrama et al. 2022a).

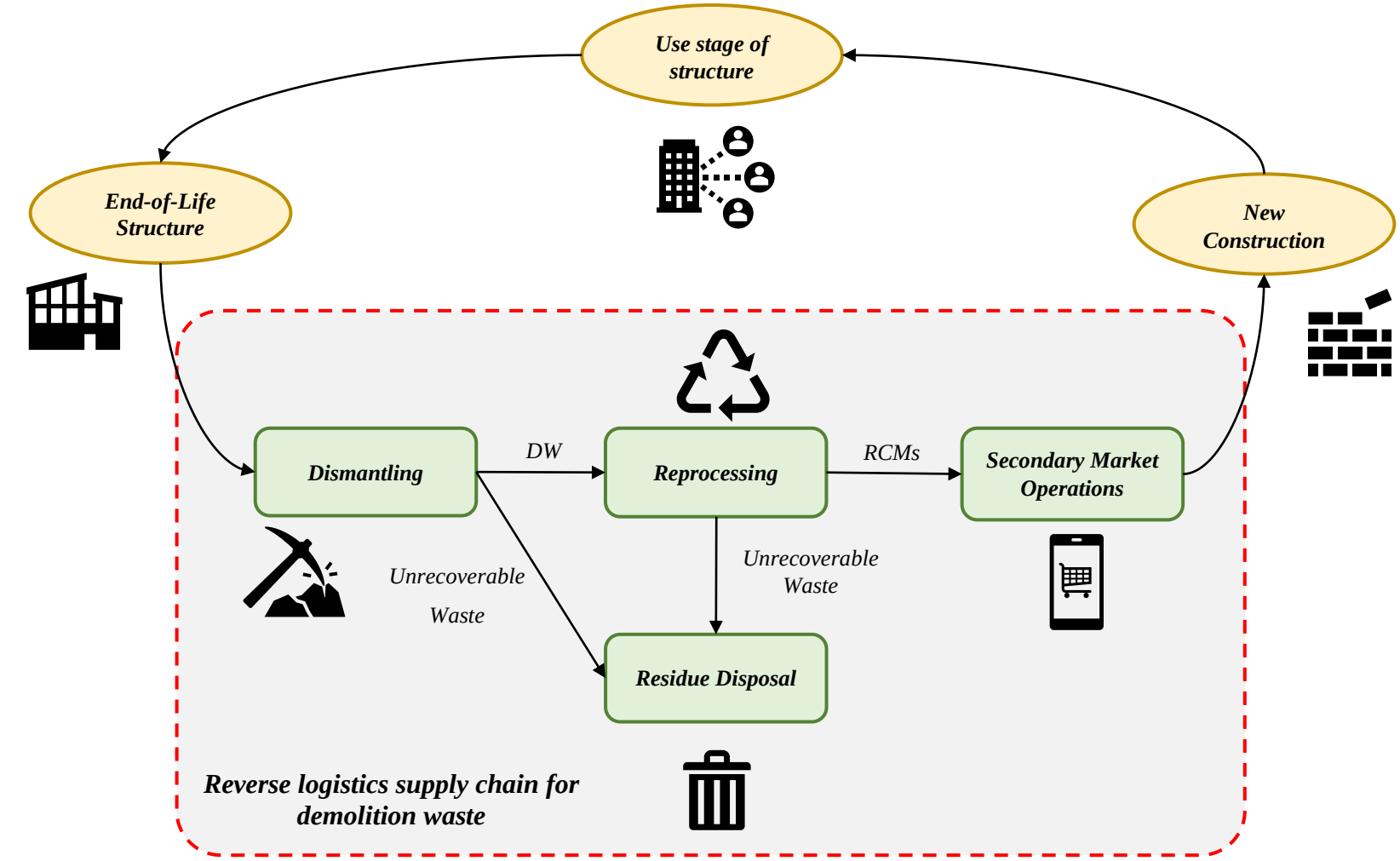
However, compared to the manufacturing industry, RL has yet to gain ground within the construction industry and remains a relatively under-explored area (Bao et al. 2023; Jayasinghe, Rameezdeen & Chileshe 2019; Tennakoon, Rameezdeen & Chileshe 2022b; Zhikun, Wang & Zou 2023). Multiple factors have contributed to this, such as the lack of well-developed markets for RCMs, heterogeneous and complex product structures, immobility and the long useful life of construction products, uncertainty in waste accumulation, wide geographic spread of the sources of DW and limited availability of material recovery facilities (MRFs) (Chileshe, Rameezdeen & Hosseini 2016; Shooshtarian et al. 2022a; Wijewickrama et al. 2021b). With limited existing studies in the domain, there is scope for further research in establishing the concept of RL within the construction industry. This, however, requires a clear understanding of the stages of a RLSC for DW. Therefore, the following section provides a detailed account of the main stages of a RLSC for DW.

2.4 Stages of the reverse logistics supply chain for demolition waste

The RLSC for DW commences with a structure that has reached its end-of-life. The end-of-life stage is reached when a built structure can no longer meet the requirements expected by its users. This can be due to physical decay (e.g., ageing, weathering, fatigue), poor quality-of-life or liveability concerns, changes in technology, oversupply of similar structures, or other changes in the broader socio-economic and regulatory environment (Thomsen & van der Flier 2011; van den Berg, Voordijk & Adriaanse 2020). When it is deemed that a structure has reached its end of life, it will be dismantled, marking the beginning of the RLSC for DW. Under the RL process, DW generated during dismantling operations is salvaged and passed through a resource recovery process to convert it into RCMs, which can be used in new construction applications. This gives a second life to DW, which would otherwise be disposed of in landfills without any value recovery.

A RLSC for DW involves a series of activities, which includes retrieving used materials, converting these materials into alternative uses, and disposing of any residual waste. Herein, four main process stages of a RLSC for DW can be identified; (1) dismantling, (2) reprocessing, (3) secondary market operations, and (4) residue disposal (Jayasinghe,

Rameezdeen & Chileshe 2022; Tennakoon, Rameezdeen & Chileshe 2022b). These stages are depicted in Figure 2.1 and are explained in detail under the following sub-sections.



DW – Demolition Waste; RCMs – Reprocessed Construction Materials

Figure 2.1: Stages of a reverse logistics supply chain for demolition waste

2.4.1 Dismantling

Dismantling an end-of-life structure is the first stage of a RLSC for DW. Although dismantling was traditionally carried out using manual methods, it has been replaced by mechanical and automated methods with advances in construction technology (Aidonis 2019). Two primary methods are used for dismantling end-of-life structures: (1) mechanical demolition (also referred to as conventional demolition) and (2) deconstruction (also referred to as selective demolition) (Aidonis 2019; Xanthopoulos et al. 2012). Mechanical demolition refers to the demolition of a structure within a short time frame using mechanical methods (Aidonis 2019). This destructive dismantling approach uses methods or tools such as explosives, wrecking balls, hydraulic crushers and pulverisers (Poon, Yu & Ng 2001; Silva, de Brito & Dhir 2017). Mechanical demolition is faster and less costly and ensures that the site is made available for new construction within a shorter timeframe (Coelho & de Brito 2011). However, this method generates large volumes of mixed or commingled waste that cannot be recovered easily, ultimately ending up in landfills without any value recovery (Chileshe et al. 2015; Hoang et al. 2022).

Alternatively, deconstruction is a much more environment-friendly dismantling approach where a structure is systematically stripped apart for high-quality salvage (Jayasinghe, Rameezdeen & Chileshe 2022). It is a non-destructive dismantling method that reduces mixed waste. Deconstruction facilitates improved waste recovery where the waste materials can be reused or recycled based on their composition (Aidonis 2019; Xanthopoulos et al. 2012). Therefore, it is the preferred dismantling method in RLSCs for DW (Chileshe et al. 2016). However, deconstruction can be time-consuming and costly, requiring more labour and advanced equipment (Jayasinghe, Rameezdeen & Chileshe 2022). This makes deconstruction less viable from an economic standpoint, and therefore, hybrid methods that combine mechanical demolition and deconstruction are used to achieve trade-offs between time, cost, and quality outcomes in dismantling (Aidonis 2019; Hoang et al. 2022; Jayasinghe, Rameezdeen & Chileshe 2022). Herein, materials that can be reused, recycled, or fetch high resale values are recovered through deconstruction, and the remaining structure is demolished mechanically (Aidonis 2019; Silva, de Brito & Dhir 2017).

DW generated in dismantling end-of-life structures is highly diversified and often contains hazardous materials that can obstruct efficient and effective waste recovery (Jayasinghe, Rameezdeen & Chileshe 2019; Purchase et al. 2022). Therefore, DW is sorted into different fractions that can and cannot be recovered (Purchase et al. 2022). Proper waste

sorting impacts the quality of RCMs, significantly reduces the volume of DW landfilled, and is therefore crucial for successful waste recovery through RLSCs for DW (Jayasinghe, Rameezdeen & Chileshe 2022; Purchase et al. 2022; Wang, J et al. 2010). There are two waste sorting methods as, on-site sorting and off-site sorting, based on the location where sorting is carried out (Chileshe, Rameezdeen & Hosseini 2016; Wang, J et al. 2010). DW can be sorted on-site at the dismantling stage or off-site at the reprocessing stage. On-site sorting is advocated from a RL perspective since early separation minimises the mixing and contamination of waste materials and ensures that higher waste recovery rates are achieved down the line (Jayasinghe, Rameezdeen & Chileshe 2019; Wang, J et al. 2010). Moreover, contractors can benefit economically from on-site waste sorting through reduced gate fees at material recovery facilities (MRFs) and landfills (Wang, J et al. 2010). Therefore, DW should ideally be sorted on-site in unison with dismantling operations to ensure the effectiveness of RL operations. However, factors such as high labour costs, space constraints within construction sites, the presence of hazardous materials, and stringent health and safety requirements limit the viability of on-site sorting (Jayasinghe, Chileshe & Rameezdeen 2019; Purchase et al. 2022). Therefore, off-site sorting is commonly practised in the industry, despite on-site sorting being the recommended approach under the principles of RL (Hossain, MU, Wu & Poon 2017). Upon dismantling and on-site sorting, DW is transported to MRFs for further sorting and reprocessing or to landfills for disposal, as shown in Figure 2.1.

2.4.2 Reprocessing

Once DW is received at a material recovery facility (MRF), it is sorted further (off-site sorting) to remove contaminants and separated into different waste fractions (e.g., concrete, masonry, metals, timber, etc.) for reprocessing. Potential alternatives for reprocessing DW include direct reuse, remanufacturing, and recycling (Chinda & Ammarapala 2016; Hosseini et al. 2015; Purchase et al. 2022). Out of these alternatives, reuse and recycling are the frequently used options for reprocessing DW (Chen, Z et al. 2016; van den Berg, Voordijk & Adriaanse 2020). Remanufacturing, a process involving the recovery of materials from high-value products, enjoys popularity within the manufacturing sector but is relatively less prominent in the construction domain (Agrawal, Singh & Murtaza 2015; Hosseini et al. 2015).

Reuse is where discarded materials are recovered and used for the same function with minimum reprocessing (Chinda & Ammarapala 2016; van den Berg, Voordijk & Adriaanse 2020). Due to its lower energy intensity and the ability to preserve the embodied

energy of materials, reuse is prioritised over recycling in the waste hierarchy as a more environment-friendly reprocessing option (Iacovidou & Purnell 2016; Jayasinghe, Rameezdeen & Chileshe 2022; van den Berg, Voordijk & Adriaanse 2020). Compared to reusing, recycling is a more commonly used method for reprocessing DW, where the waste materials are reprocessed into raw materials for manufacturing new products (Iacovidou & Purnell 2016). Recycling is a popular reprocessing option for materials such as concrete, steel, and timber (Purchase et al. 2022; Saghafi & Teshnizi 2011). However, a problem with recycling is that, in most cases, DW is downcycled, where the resulting recycled product is considered to have inferior characteristics and is therefore used for lower-grade applications than its original use (Hosseini et al. 2015; Nunes, Mahler & Valle 2009). An example is recycled concrete aggregates (RCAs), primarily used as sub-base materials in road construction with limited use as virgin aggregate replacements in new concrete mixes (Kibert 2016). Moreover, recycling has an energy disadvantage since a significant proportion of the initially invested embodied energy is lost during the process (van den Berg, Voordijk & Adriaanse 2020). Despite these drawbacks, recycling is still more beneficial than discarding DW in landfills.

Incineration or energy recovery, which converts waste to energy, is also considered an option for reprocessing DW (Tam et al. 2018). However, this is not an effective option for DW recovery since it does not generate any RCMs and, therefore, sits just above disposal in the waste hierarchy (Caldera, Ryley & Zatyko 2020). Selection of the suitable reprocessing option from the alternatives discussed can depend on factors such as economic feasibility, waste composition, purity of waste materials, market demand for RCMs and relevant governance frameworks (Caldera, Ryley & Zatyko 2020). Upon reprocessing, the RCMs derived are tested and graded to verify their compliance with the relevant standards and specifications and then dispatched to secondary markets for use in new construction projects (Behera et al. 2014; Jayasinghe, Chileshe & Rameezdeen 2019). Any residual waste that results after reprocessing is sent to licensed landfills for safe disposal (Jayasinghe, Chileshe & Rameezdeen 2019; Purchase et al. 2022).

2.4.3 Secondary market operations

Successful RL requires more than simply collecting and reprocessing DW. It requires a well-developed consumption process, which is where secondary market operations come into play (Shooshtarian et al. 2020a; Yu et al. 2021). At this stage, RCMs derived from reprocessing DW are delivered back into the construction materials market to be used in new construction applications, ultimately forming a circular flow of resources that avoids

or minimises waste sent to landfills (Jayasinghe, Rameezdeen & Chileshe 2019; Yu et al. 2021). Secondary market operations are essential to ensure the long-term sustainability of RLSCs for DW since the entire process is driven by the market demand for RCMs (Ding, Nie & Wu 2022; Silva, de Brito & Dhir 2017).

Typical RCMs found in secondary markets include materials such as RCAs, bricks, timber, and steel (Behera et al. 2014; Caldera, Ryley & Zatyko 2020; Iacovidou & Purnell 2016; Niu et al. 2021). The market for metallic materials such as steel is more developed due to the higher recycling potential inherent to its unique material properties and higher market value (Caldera, Ryley & Zatyko 2020). However, metallic materials generally account for a small percentage of the DW stream (Sustainability Victoria 2020). Past studies indicate growing opportunities for using RCAs as materials for constructing road bases and as replacements for virgin aggregates in concrete mixes (Jayasinghe, Chileshe & Rameezdeen 2019; Purchase et al. 2022; Silva, de Brito & Dhir 2017). Other RCMs show a low market development, with materials such as timber being incinerated for energy generation due to the low demand for its reprocessed forms (Brol, Dawczynski & Adamczyk 2015; Niu et al. 2021; Pickin et al. 2020).

While secondary markets are proliferating in industries such as smartphones and pharmaceuticals (Guo et al. 2020), recent studies have shown that secondary markets for RCMs are underdeveloped (Chen, W et al. 2019; Jayasinghe, Chileshe & Rameezdeen 2019; Tennakoon, Rameezdeen & Chileshe 2022a). There can be multiple reasons behind this low market development. For example, using RCMs for high-grade applications is restricted in some countries, which limits marketability (Hahladakis, Purnell & Aljabri 2020). Negative perceptions regarding the quality and performance of RCMs can also weaken purchase intentions and limit the uptake of RCMs (Bao, Lee & Lu 2020; Oyedele, Ajayi & Kadiri 2014). Moreover, RCMs are under significant competition from virgin materials since there is little to no price difference between virgin materials RCMs in most cases (Chileshe, Rameezdeen & Hosseini 2016; Jin et al. 2017). Therefore, secondary markets for RCMs require more attention in areas such as enhancing consumer awareness, improving material quality, incentivising, and supportive regulatory frameworks (Jayasinghe, Chileshe & Rameezdeen 2019; Nunes, Mahler & Valle 2009; Tennakoon, Rameezdeen & Chileshe 2022a).

2.4.4 Residue disposal

At this stage, DW that cannot be recovered will be disposed of safely in landfills. A key objective of RLSCs for DW is to minimise this volume of waste sent to landfills. As shown in Figure 2.1, waste that is classified as unrecoverable during on-site and off-site sorting and any residual waste after reprocessing is disposed of at landfills. These materials mainly constitute hazardous or contaminated waste that cannot be recovered safely for use in new construction applications (Wijewickrama et al. 2022a). Asbestos, insulation materials (e.g., rock wool), and treated timber are some hazardous waste materials that should be disposed of systematically following extensive safety controls to mitigate potential health, safety, and environmental risks (Chileshe, Jayasinghe & Rameezdeen 2019; Iacovidou & Purnell 2016). Moreover, when inert waste such as concrete is contaminated with hazardous materials, the entire mixture is treated as hazardous and disposed of with adequate safety controls (Iacovidou & Purnell 2016; Wijewickrama et al. 2022a).

With the rapid growth in construction and resulting high waste generation rates, many countries have imposed landfill levies to discourage landfilling of DW (Caldera, Ryley & Zatyko 2020; Rose & Stegemann 2018). However, such levy schemes should be designed cautiously since they can encourage illegal dumping (Jayasinghe, Rameezdeen & Chileshe 2022). It is important to note that landfills should be designed, operated and managed meticulously to avoid negative externalities such as dust, odour, health impacts, illegal dumping and contamination of water, soil, and air resources (Jayasinghe, Rameezdeen & Chileshe 2022).

2.5 Stakeholders of the reverse logistics supply chain for demolition waste

Literature on RLSCs for DW has identified parties including demolition contractors, waste processors, landfill operators, end-users of RCMs (i.e., architects, engineers, builders, clients), government, non-governmental bodies (e.g., professional institutes, sustainability rating bodies) and educational institutes as stakeholders of the RLSC for DW (Brennan et al. 2014; Jayasinghe, Chileshe & Rameezdeen 2019; Shooshtarian et al. 2020a; Tennakoon, Rameezdeen & Chileshe 2022b; Wijewickrama et al. 2022b). Herein, demolition contractors, waste processors, landfill operators, and end-users are directly involved in the material movement through the RLSC from dismantling to secondary markets. Alternatively, stakeholders such as the government, non-governmental bodies and educational institutes are not directly involved in material movement but can influence the process and its outcomes. Following the seminal study on RL by Carter, CR and Ellram

(1998), this second group of stakeholders can be broadly divided into two as: government and interest aggregators. Figure 2.2 depicts the involvement of these stakeholders in the RLSC for DW.

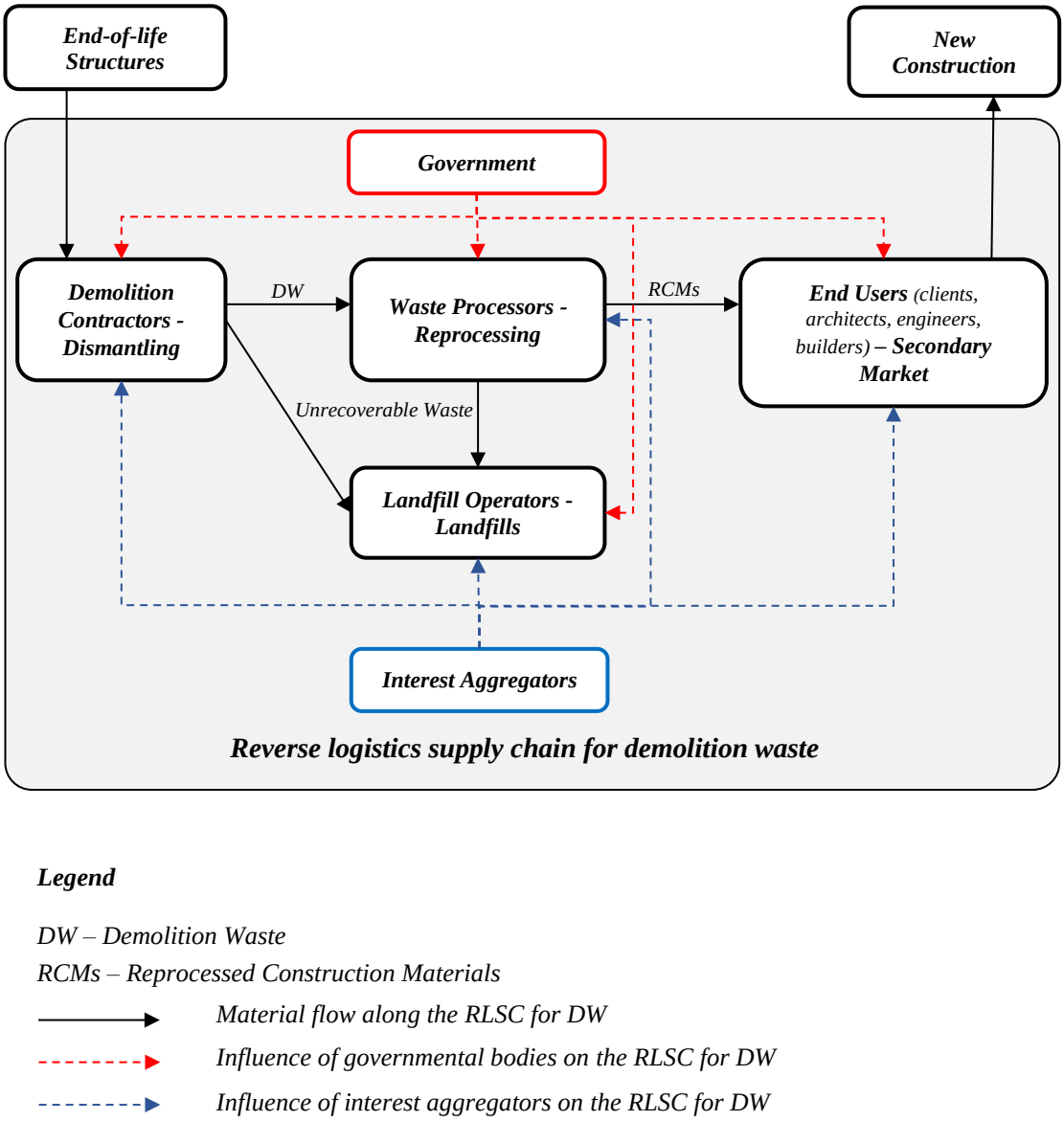


Figure 2.2: Stakeholders of the reverse logistics supply chain for demolition waste (Adapted from: Carter, CR and Ellram (1998); Mak et al. (2019))

The first stage of the RLSC for DW, dismantling end-of-life structures, is carried out by demolition contractors (Brennan et al. 2014; Tennakoon, Rameezdeen & Chileshe 2022b). Upon dismantling, the demolition contractors sort the DW on-site where possible (on-site sorting) to separate it into recoverable and unrecoverable fractions. Typically, the fractions of DW that can be recovered are directed to waste processors for reprocessing, while the unrecoverable fractions are disposed of in landfills. However, it is important to note that

the choice between reprocessing or landfilling is often determined by the economic feasibility of the individual options (Caldera, Ryley & Zatyko 2020). In some instances, demolition contractors may opt to landfill all the DW generated if it proves to be more cost-effective than taking it to a waste processor. Demolition contractors may use their own transportation facilities to transport the DW or contract with logistics service providers or waste processors to collect the DW on their behalf (Schultmann & Sunke 2007).

The next stage, which is reprocessing, is undertaken by specialised waste processors (Brennan et al. 2014; Tennakoon, Rameezdeen & Chileshe 2022b). Waste processors occupy a central position within the RLSC for DW, forming links with demolition contractors, who generate DW and end users in the secondary market, who use RCMs (Tennakoon, Rameezdeen & Chileshe 2022b). Waste processors are responsible for processing DW and marketing RCMs. They accept pre-sorted waste or mixed/commingled waste from demolition contractors. Subsequently, the waste acquired is further sorted, reprocessed, tested, and graded to produce RCMs, which are dispatched to the secondary market to be used in new construction applications, while any residual waste from reprocessing is disposed of in landfills. As the party responsible for managing landfills, landfill operators accept unrecoverable waste from both dismantling and reprocessing stages and dispose of it safely to minimize negative externalities such as leachate discharge and air pollution (Jayasinghe, Rameezdeen & Chileshe 2022).

The secondary market operations include stakeholders such as clients, architects, engineers, and builders responsible for the uptake of RCMs. As the end-user of and the party making the financial commitment for built facilities, client preferences are crucial in determining the uptake of RCMs (Shooshtarian et al. 2020a). Similarly, architectural, engineering, and construction professionals also influence decisions around materiality (RIBA 2020). Architects and engineers are at the forefront of selecting RCMs and are, therefore, important stakeholders in the secondary market stage (Oyedele, Ajayi & Kadiri 2014; Shooshtarian et al. 2020a). With procurement methods such as Design-and-Build gaining popularity, builders are also increasingly involved in material selection decisions, and their knowledge and experience have become central to enhancing the uptake of RCMs (Shooshtarian et al. 2020a).

Although not directly involved in moving materials along RLSCs for DW, the government is an essential stakeholder in this process. Governmental bodies at various levels of governance can promote and drive the use of RCMs in different ways, including

developing standards and specifications for RCMs, building awareness, and stimulating secondary markets (Bao, Lee & Lu 2020; Ding, Nie & Wu 2022; Oyedele, Ajayi & Kadiri 2014; Shooshtarian et al. 2020a). Moreover, governmental bodies are responsible for regulating the DW recovery industry by developing procedures for handling and processing DW, producing health and safety guidelines and ensuring that such requirements are adhered to by the relevant parties (Tennakoon, Rameezdeen & Chileshe 2022b). Finally, interest aggregators such as non-governmental bodies can also influence RLSC operations (Wijewickrama et al. 2022b).

2.6 Significance of the market uptake of reprocessed construction materials in ensuring the success of reverse logistics supply chains for demolition waste

Seminal studies on RL by authors such as Carter, CR and Ellram (1998), Fleischmann (2001), and de Brito and Dekker (2004) have asserted that the success of RLSCs depends on having a matching market for reprocessed materials. This idea is supported by multiple studies on RL from the construction industry, which have emphasised that the market uptake of RCMs can directly impact the success of RLSCs for DW. Herein, Yu et al. (2021) highlighted that successful RL requires more than the mere collection and reprocessing of waste materials; it requires a robust consumption process as well. According to the authors, neglecting the consumption or market aspect of the RL equation could undermine the long-term viability of RLSC operations. Spoerri et al. (2009) and Yuan, Shen and Wang (2011) identified the presence of a functional market with sufficient demand for RCMs as a crucial prerequisite for the success of recycling schemes and maintaining high recovery rates for DW. Similarly, Srour, Chong and Zhang (2012) acknowledged the presence of markets for RCMs as one of the major factors underpinning the viability of DW recovery schemes. Silva, de Brito and Dhir (2017) and Ding, Nie and Wu (2022) affirmed that as the mainstream applications of RCMs increase, there would be a corresponding increase in focus on recovering DW, thus underscoring the interdependence between the market uptake of RCMs and the growth of RLSCs for DW. Adding to this, Zhang, C et al. (2020) emphasised the significance of sustainable procurement as a key strategy to promote successful waste recovery processes. Moreover, Shooshtarian et al. (2022b) and Tennakoon, Rameezdeen and Chileshe (2022a) contended that the uptake of RCMs contributes directly towards improving waste recovery rates, and it is, therefore, imperative to develop markets for RCMs if waste recovery processes are to

be effective. Findings from these studies make it abundantly clear that well-developed markets for RCMs play a crucial role in ensuring the success of RLSCs for DW.

The importance of developing markets for reprocessed materials to achieve success in waste recovery has also been recognized in the Australian context. The China National Sword Policy, which came into effect in 2018, banned the import of waste materials into China (Pickin et al. 2020). This created many problems for the Australian waste management industry since China was one of the leading destinations for Australian waste materials (New South Wales Environmental Protection Agency 2022; Pickin et al. 2020). Anti-waste movements in countries such as Malaysia, the Philippines, and Thailand further limited the options for exporting Australian waste (Shooshtarian et al. 2020b). Aligned with these international policy changes, the Department of Climate Change, Energy, the Environment and Water (DCCEEW) in Australia also began to regulate the export of waste materials such as glass, plastics, and tyres in 2021 with further regulations for paper and cardboard expected to be implemented by 2024 (Department of Climate Change Energy the Environment and Water 2022). With these restrictions on waste exports, Australia has been compelled to explore alternative approaches to waste management within its borders. To ensure the effectiveness of these efforts, the importance of establishing robust domestic markets for reprocessed materials has been acknowledged.

Within this background, the importance of developing markets and increasing the uptake of reprocessed materials has been captured in multiple Australian policy documents related to waste management through RL. The Australian National Waste Policy published in 2018 proposed multiple strategies to minimise waste generation by focusing on the waste hierarchy and the circular economy principles of promoting the recurrent use of existing resources (Commonwealth of Australia 2018; Shooshtarian et al. 2022b). Herein, the policy has emphasised the importance of increasing the use of and building demand and markets for reprocessed materials in Australia, and strategies 8 and 9 of the policy on adopting sustainable procurement by governments, businesses, and individuals highlight this aspect. Similar requirements are evident in the National Waste Policy Action Plan 2019, where Target Area 04 specifically focuses on increasing the use of recycled content by governments and industry (Australian Government, State and Territory Governments & Australian Local Government Association 2019).

Similar aspects have been underlined in waste management policy documents developed at state and territory levels, stressing that sustainable procurement of reprocessed materials plays a pivotal role in waste management processes (Shooshtarian et al. 2022b). A

prominent example is the “Recycled First” policy enacted by the State Government in Victoria to prioritise using recycled materials in infrastructure projects (ecologiQ and Victoria State Government 2020). These findings suggest that the market uptake of reprocessed materials has been recognised as a crucial aspect in ensuring the success of RL programs. In fact, the latest annual report from Sustainability Victoria has highlighted that producing reprocessed materials is merely one piece of the puzzle of sustainable waste management and that it is equally important to develop markets for these materials simultaneously (Sustainability Victoria 2022).

2.7 The problem of low market uptake of reprocessed construction materials

The previous section emphasised the importance of having a strong market demand for RCMs to ensure the success of RLSCs for DW. Despite this, a review of extant literature showed that the market uptake of RCMs is limited, which has hindered the effectiveness of RLSCs for DW. As elaborated in the following sections, this problem is evident in both the global and Australian contexts.

2.7.1 Global context

Bao and Lu (2020) highlighted that despite developing policies for promoting RCMs, markets for such materials are growing slowly in most economies. Findings from studies focusing on the waste recovery sectors of different countries support this assertion. According to a UK-based study by Oyedele, Ajayi and Kadiri (2014), RCMs have a low acceptance level within the construction industry and, therefore, these materials are under-utilised in construction projects. Schut, Crielaard and Mesman (2015) reported that, although around 95% of waste from the construction industry is recovered in the Netherlands, only 3-4% is used in high-grade applications. As per the authors’, most recovered materials are put to lower-grade use or are disposed of without further use. Based on a survey of the Chinese construction industry, Jin et al. (2017) concluded that there is an apparent lack of demand for RCMs in the Chinese construction market. This is supported further by Huang et al. (2018), who identified under-developed and immature markets as a critical barrier to reprocessing DW in China. An Indonesian study by Sembiring (2018) ascertained that the use of RCMs is not commonplace and that the construction industry is more focused on achieving efficiency and economic gains rather than promoting sustainable material use. Sáez and Osmani (2019) analysed waste data from the European Union (EU) and identified undeveloped RL and poor market readiness

for RCMs as key challenges for waste recovery. Through a review of studies on the Indian waste management industry, Jain (2021) revealed that despite having waste management rules enacted, the widespread uptake of RCMs is limited. A recent study by Ding, Nie and Wu (2022) highlighted that despite the potential of RLSCs to convert a significant percentage of DW into new construction materials, most stakeholders are not willing to use these materials, which hampers the growth of waste markets. Collectively, these studies emphasise that the uptake of RCMs remains limited across many countries. This low uptake of RCMs acts as a bottleneck in moving DW through RLSCs for DW and undermines the long-term viability of waste recovery processes.

2.7.2 Australian context

Following the increase in government attention on adopting circular economy principles and minimising carbon emissions (e.g., the target of the Australian government on achieving net-zero emissions by 2050), the C&DW recovery rate in Australia has increased over the last few years. According to the Australian National Waste Report 2020, the C&DW recovery rate increased by 16% from 2007 to 2019 (Pickin et al. 2020). However, multiple studies conducted within the same period indicate that the uptake of RCMs has *not* increased in line with this increase in waste recovery rates.

Based on a study of barriers towards implementing RL in Australian construction organisations, Chileshe et al. (2015) identified that the uptake of RCMs in new construction applications is limited and determined this to be the single most significant barrier to adopting RL practices within the Australian construction industry. Similarly, analysing factors impeding waste management in Australian construction projects, Udawatta et al. (2018) underlined a lack of market demand for RCMs as a primary barrier to implementing waste management practices. This factor was highlighted by 31% of the interviewees who participated in the study. Park and Tucker (2017) identified an imminent lack of demand for RCMs in Australian construction markets through a review of research targeting the Australian waste management industry. The authors went on to mention that the use of RCMs has not proliferated in Australia and that the effectiveness of the waste management industry could be improved if the market demand for RCMs were to increase. Apart from these research studies, documentaries from 2017, such as “War on Waste” and “Four Corners – Trashed” by the Australian Broadcasting Corporation (ABC), also highlighted the low uptake of RCMs in Australia. These documentaries noted situations where waste materials received for reprocessing were dumped in illegal landfills or stored away in warehouses owing to the lack of demand for their reprocessed forms.

More recently, a study by Ratnasabapathy, Alashwal and Perera (2021) on waste trading practices in the Australian construction industry found that markets for RCMs are not well-established and are not secure, thus limiting the use of RCMs. On a similar note, Shooshtarian et al. (2020b) concluded that despite ongoing market development efforts, the performance of the markets for RCMs in Australia is far from perfect. Sustainable procurement guidelines focusing on RCMs were introduced only recently in Australia and, therefore, have not yet gained ground in the industry (Shooshtarian et al. 2022b). Moreover, such guidelines are developed by individual state governments and do not have universal application across Australia. Owing to such discrepancies, Pickin et al. (2020) noted an imbalance in market development for RCMs across different states in Australia, with some states having quite mature markets and others showing poor levels of market development.

Together, these studies indicate that, similar to the global scenario, the markets for RCMs are also underdeveloped in Australia, and the uptake of RCMs remains limited. This hinders the success of RLSCs for DW and is an issue that must be addressed to ensure DW recovery efforts proceed smoothly.

2.8 Promoting the uptake of reprocessed construction materials: A pro-environmental behaviour perspective

As revealed in the previous section, the uptake of RCMs remains limited, including within the Australian construction industry, despite its significance in ensuring the success of RLSCs for DW. Therefore, it is crucial to understand how the uptake of RCMs can be promoted among end-users. To better understand this phenomenon, the current study looked at the uptake of RCMs through the lens of pro-environmental behaviour.

2.8.1 Understanding the uptake of reprocessed construction materials as a pro-environmental behaviour

Stern (2000) defined pro-environmental behaviours as behaviours that "*change the availability of materials or energy from the environment or alters the structure and dynamics of ecosystems or the biosphere* (p. 408)." According to the authors, purchasing practices that consider the environmental impact of production processes, e.g., the purchase of recycled products, can be considered a form of pro-environmental behaviour. Building upon the work of Stern (2000), Steg and Vlek (2009) later defined pro-environmental behaviour as "*behaviour that harms the environment as little as possible or*

even benefits the environment (p. 309)." A more recent study by Grimmer, Kilburn and Miles (2016) defined pro-environmental behaviour to include:

> …the use of environmentally responsible products; products that minimise environmental impact; products from firms with good environmental reputations, or products whose production process implies biodegradable, carbon neutral or recycled inputs (p. 1582).

Based on these definitions, the uptake of RCMs can be viewed as a pro-environmental behaviour since RCMs are environmentally responsible products made using secondary inputs (i.e., DW) that have low material and energy demands compared to their virgin counterparts. Moreover, the uptake of RCMs minimises the negative environmental impacts of construction activities by reducing landfilled waste and the demand for virgin materials. The decision to consider the uptake of RCMs as a pro-environmental behaviour is supported by Agrawal, Singh and Murtaza (2016) where the authors acknowledged that the demand for reprocessed materials is heavily dependent on user behaviours.

2.8.2 An approach for promoting pro-environmental behaviours

Promoting pro-environmental behaviours, such as the uptake of RCMs, requires a structured approach (Steg & Vlek 2009; Stern 2000). Herein, the four-step approach for promoting pro-environmental behaviours proposed by Stern (2000) could be considered. According to this approach, the first step is to select environmentally significant target behaviours (i.e., pro-environmental behaviours) that must be promoted. This should be followed by an analysis of the selected behaviours to identify the responsible actors and actions. Then, factors that determine pro-environmental behaviours (discussed in detail under Section 2.8.2.3) should be considered to identify possible factors that limit the behaviours from the actors' standpoint. Next, potential strategies for promoting the behaviours should be explored directly with representatives of the population whose behaviour is to be changed. Although not highlighted explicitly, the authors also emphasised the importance of continually monitoring the effectiveness of the strategies once they are implemented and adjusting them accordingly. A similar framework for promoting pro-environmental behaviours was proposed by Steg and Vlek (2009), which involves identifying the pro-environmental behaviours to be changed, examining the main factors limiting the selected behaviours, designing and applying strategies to change the selected behaviours, and systematically evaluating the effectiveness of the strategies applied. This study builds on a combination of these two approaches, as outlined in Figure 2.3, to understand how the uptake of RCMs can be promoted. How each stage of this

combined approach applies to the current study is explained in detail through the ensuing sections.

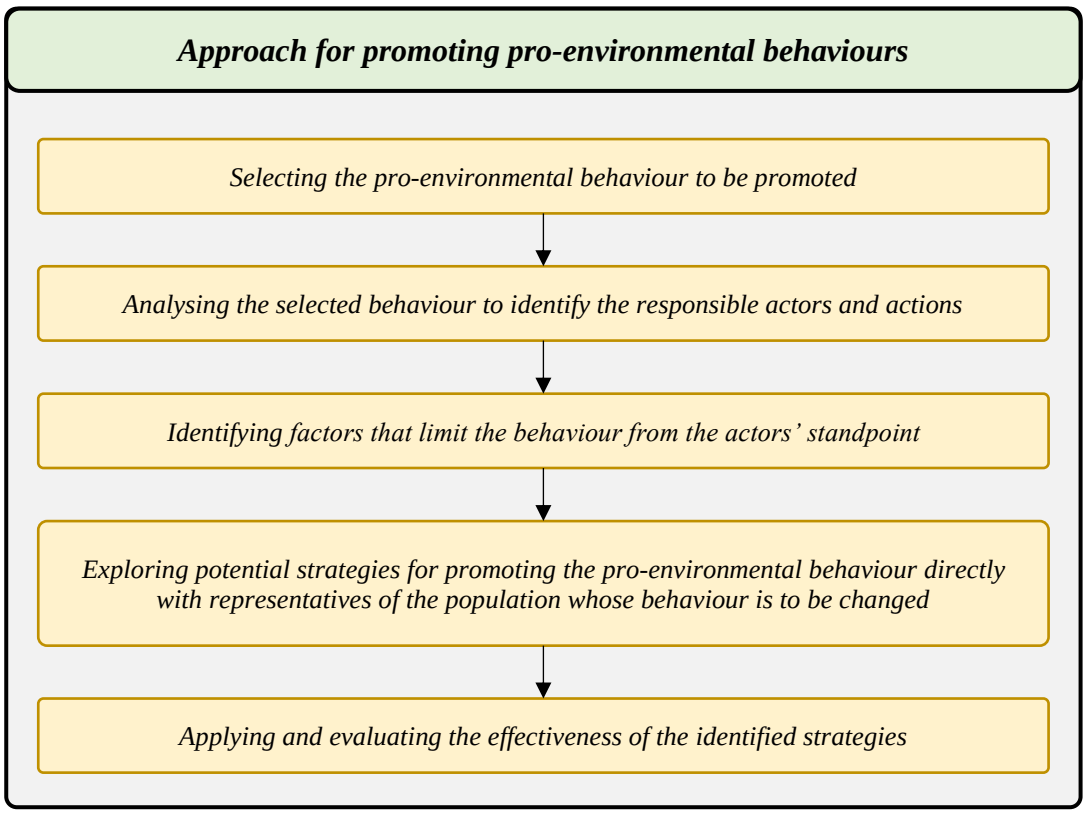


Figure 2.3: Approach for promoting pro-environmental behaviours (Adapted from Stern (2000) and Steg and Vlek (2009))

2.8.2.1 Selecting the pro-environmental behaviour to be promoted

The significance of the market uptake of RCMs in ensuring the success of RLSCs for DW was affirmed through Section 2.6. However, literature findings highlighted in Section 2.7 showed that the uptake of RCMs is limited globally and in Australia, thus undermining the viability of DW recovery processes. Therefore, the **pro-environmental behaviour to be promoted in the context of this study was considered as the uptake of RCMs**, which would ultimately help to ensure the success of RLSCs for DW. Improving the uptake of RCMs can significantly benefit the environment by reducing the volumes of DW being landfilled and minimising the demand for virgin materials. Since construction activity continues to expand, such a shift towards RCMs can have a notable impact on mitigating the industry's negative environmental impacts. Therefore, promoting the uptake of RCMs is worthwhile since it aligns with the assertion of Klaniecki, Wuropulos and Hager (2016), who mentioned that efforts to promote pro-environmental behaviours should focus on behaviours with a large environmental impact and are performed by many.

2.8.2.2 Identifying the responsible actors and actions

According to Figure 2.2 (Stakeholders of the RLSC for DW), the end-users of RCMs include architects, engineers, builders (i.e., Architecture, Engineering, and Construction (AEC) professionals), and construction clients. Herein, AEC professionals can have a significant influence on decisions around materiality in construction projects (RIBA 2020). With their direct involvement in developing project designs and specifications, architects and engineers are at the forefront in terms of their ability to promote the uptake of RCMs (Li, YY et al. 2014; Shooshtarian et al. 2020a). Builders can also influence the uptake of RCMs, and their practical knowledge and experience are central to promoting the widespread use of such materials (Shooshtarian et al. 2020a). Further, with procurement methods such as Design-and-Build gaining popularity, builders are increasingly involved in project design and material selection. However, prior studies have shown that AEC professionals rarely consider using RCMs due to reasons such as negative perceptions, lack of awareness, higher costs, and issues with access to such materials (Oyedele, Ajayi & Kadiri 2014; Tennakoon, Rameezdeen & Chileshe 2022a). As the party initiating a construction project and making the financial commitment, clients can also influence decisions around materiality. However, unless well-versed in construction technologies, clients usually look to AEC professionals for advice on material selection. Therefore, this study identified and considered **AEC professionals** (hereafter referred to as construction professionals (CPs)) **as the key actors responsible** for promoting the uptake of RCMs since they are **primarily responsible for selecting materials for construction projects**. The decision to consider AEC professionals as the key actors responsible for material selection was further corroborated by studies such as Oyedele, Ajayi and Kadiri (2014) and Shooshtarian et al. (2020a), that considered designers (architects and engineers) and builders as the major stakeholders involved in selecting materials for construction projects.

2.8.2.3 Identifying the factors that limit the pro-environmental behaviour

Section 2.8.2.1 identified the pro-environmental behaviour to be changed as the uptake of RCMs, and Section 2.8.2.2 showed that construction professionals (CPs) are the key actors whose behaviours are to be changed to promote the uptake of RCMs. The focus of this section was to identify factors that limit the uptake of RCMs among CPs when selecting materials for construction projects. To develop a more coherent understanding of these factors, theories on pro-environmental behaviour were referred to ahead of the study to identify factors that determine pro-environmental behaviours. According to Steg and Vlek (2009), these underlying factors can either promote or inhibit pro-environmental

behaviours. This study contends that the negative influences of such factors can inhibit the uptake of RCMs among CPs.

The study of behaviour in social sciences takes two distinct approaches (Guagnano, Stern & Dietz 1995). One approach studies behaviour as a function of processes internal to an individual, whereas the other considers behaviour to be a function of the context. Most behavioural theories have been developed along these respective lines of thought, and this distinction is also evident in research on pro-environmental behaviour. This was affirmed by Ertz, Karakas and Sarigöllü (2016) and Zhang, X and Dong (2020), who identified two sets of factors used to predict pro-environmental behaviours; the first is related to personal factors or actor-related factors (e.g., attitudes of the actor towards a specific pro-environmental behaviour) and the second is related to contextual factors (e.g., availability, quality, price of different behavioural alternatives). The Theory of Planned Behaviour is the most influential theoretical framework used in the personal domain to explain the effect of personal factors on pro-environmental behaviour, followed by theories such as the Norm-Activation Model, Value-Belief-Norm Theory and New Environmental Paradigm (Ertz, Karakas & Sarigöllü 2016; Steg & Vlek 2009; Zhang, X & Dong 2020). Alternatively, theories such as Modern Planning Theory and Performance-Dependant Incentive Theory have been used in the contextual domain to explain the effect of contextual factors on pro-environmental behaviour (Ertz, Karakas & Sarigöllü 2016).

Although these two streams of studies offer valuable insights, focusing on personal factors alone ignores the effect of contextual factors on pro-environmental behaviour while focusing exclusively on contextual factors underrepresents the effect of personal factors on pro-environmental behaviour (Carrington, Neville & Whitwell 2010; Ertz, Karakas & Sarigöllü 2016; Steg & Vlek 2009; Stern 2000). Studies have shown that pro-environmental behaviours, in reality, are determined by both personal and contextual factors in unison. For example, Heath and Gifford (2002) showed that bus ridership improved significantly after introducing a universal bus pass in addition to driving changes in attitudes towards transportation modes. Therefore, a more promising approach is to consider pro-environmental behaviour as an outcome of the combined effect of personal and contextual factors (Ertz, Karakas & Sarigöllü 2016). With this realization, another stream of theories emerged that explains the integrated effect of personal and contextual factors on pro-environmental behaviour (Carrington, Neville & Whitwell 2010; Ertz, Karakas & Sarigöllü 2016; Guagnano, Stern & Dietz 1995; Stern 2000; Zhang, X & Dong 2020). The use of this integrated approach towards analysing pro-environmental

behaviours is advocated since "*theories from distinct perspectives tend to view individuals as either atomistic agents autonomous of social structure or automatons programmed by forces beyond their comprehension or control*" (Guagnano, Stern & Dietz 1995, p. 700). Accordingly, the Attitude-Behaviour-Context (ABC) Theory was presented by Guagnano, Stern and Dietz (1995), which explains the combined effect of both personal (Attitudes) and contextual factors (Context) on pro-environmental behaviour.

ABC Theory has been built upon the Lewinian truism that behaviour is a function of an organism and its environment (Ertz, Karakas & Sarigöllü 2016). It draws from the work of Stern and Oskamp (cited in Guagnano, Stern & Dietz 1995), who contended that environmentally relevant action is an outcome of the combined effect of personal factors, such as attitudes of individuals and contextual factors such as economic forces, physical structures and social institutions. ABC Theory posits that environmentally relevant actions or behaviours (B) are associated with attitudes (A) of individuals as well as the context (C). Where other things are equal, actions that are inconvenient, complex, or expensive (negative C) would be relatively rare, whereas those that are convenient, straightforward, and inexpensive (positive C) would be very common. Similarly, with other things being equal, actions strongly favoured by individuals (positive A) would be more prevalent, whereas those strongly opposed (negative A) would be rare. ABC Theory has the unique ability to provide a thorough account of pro-environmental behaviour by combining the effect of both personal and contextual factors, which is the strength of this model compared to other behavioural theories (Ertz, Karakas & Sarigöllü 2016; Okumah et al. 2020).

Stern (2000) extended ABC Theory to identify four main types of factors that can influence pro-environmental behaviours. These include attitudinal factors, personal capabilities, habits or routines, and contextual factors. The first three types of factors relate to individuals or actors responsible for pro-environmental behaviours, while the fourth relates to external conditions or context within which the behaviour is undertaken. According to the author, individuals can be constrained from undertaking pro-environmental behaviours due to the different ways in which these factors interact. Therefore, all four types of factors must be considered to arrive at a comprehensive understanding of the factors that determine specific pro-environmental behaviours. The four types of factors are explained in detail in the following sections.

2.8.2.3.1 Attitudinal factors

Attitude can be considered as the way in which an individual views or evaluates something or someone; a predisposition or a tendency of an individual to respond positively or negatively towards a particular idea, object, person, or situation (Vargas-Sánchez, Plaza-Mejía & Porras-Bueno 2016). Attitudinal factors that influence pro-environmental behaviours can include the general predisposition to act with pro-environmental intent, which can affect all behaviours that an individual considers to be environmentally significant (Ertz, Karakas & Sarigöllü 2016; Stern 2000). It can also include other non-environmental attitudes (e.g., about product quality), perceived personal costs and benefits of action, and behaviour-specific beliefs and norms (Stern 2000). Pre-existing tendencies to consider pro-environmental behaviours favourably increase the propensity to perform such behaviours, while unfavourable tendencies can discourage it (Ertz, Karakas & Sarigöllü 2016).

2.8.2.3.2 Personal capabilities

Considering individuals' capabilities could be important for promoting pro-environmental behaviours that depend strongly on particular capabilities since the lack of these capabilities could deter individuals from engaging in such behaviours (Stern 2000). Personal capabilities can include the knowledge and skills required to undertake pro-environmental behaviours and the availability of other general capabilities and resources such as time, money, and social status (Stern 2000). Behaviours that require specialised knowledge or skills are most likely influenced by whether or not the individual undertaking the behaviour possesses those capabilities (Stern 2000). The availability of time to act is considered a personal capability, and the more time available for an individual to act environmentally, the higher their tendency to act accordingly (Ertz, Karakas & Sarigöllü 2016). For example, the likelihood of a consumer pursuing a green product was found to increase when the consumer had ample time to review the product information (Grimmer, Kilburn & Miles 2016). Pro-environmental behaviours also depend on individuals' economic resources, and studies have shown that costly pro-environmental behaviours are more likely to be adopted by those with higher disposable incomes (Grimmer, Kilburn & Miles 2016).

2.8.2.3.3 Habits or routines

Most theories on pro-environmental behaviour have been developed with the assumption that individuals make reasoned choices based on the costs and benefits of alternative

courses of action (Steg & Vlek 2009). However, prior research has shown that many pro-environmental behaviours are a matter of personal habit or routine and tend to be highly repetitive (Stern 2000; Zhang, X & Dong 2020). Habits have been defined as "*a form of automaticity in responding that develops as people repeat actions in stable circumstances*" (Verplanken & Wood 2006, p. 91). When engaging in a particular action for the first time, people generally decide what actions should be performed and how they should be performed to achieve the desired outcome. However, as these actions become repeated, decision-making recedes and gives way to automatic habitual responses. Therefore, as a specific behaviour is repeatedly performed, individuals might not see the need to reconsider or re-evaluate that behaviour, which makes changing such behaviours difficult (Mair & Bergin-Seers 2010). Changing habitual behaviours requires these established habits to be broken down to allow the creation of new ones (Dahlstrand & Biel 1997). Consequently, any environmentally unfriendly habits must be broken down to allow the establishment and growth of pro-environmental behaviours.

2.8.2.3.4 Contextual factors

Pro-environmental behaviours do not depend on personal factors alone and have external conditions associated with them, which can either inhibit or facilitate such behaviours. For example, higher recycling rates have been noted among people with access to recycling programs than those without access (Guagnano, Stern & Dietz 1995), indicating that access to recycling is an external condition that influences recycling behaviour. ABC Theory refers to these external conditions as contextual factors, which can include features of the broad social, economic, and political environment (Guagnano, Stern & Dietz 1995; Stern 2000). Material costs, pricing regimes, product quality and availability, technological constraints, government regulations and other legal and institutional factors all fall under contextual factors that affect pro-environmental behaviours (Ertz, Karakas & Sarigöllü 2016; Grimmer, Kilburn & Miles 2016; Steg & Vlek 2009; Stern 2000; Zhang, X & Dong 2020).

2.8.2.3.5 ABC Theory in the current study

In this study, ABC Theory was used to guide the identification and classification of factors that could limit the uptake of RCMs among CPs involved in material selection. According to ABC Theory, the uptake of RCMs among CPs can potentially be limited due to personal factors such as attitudes, personal capabilities and habits or routines, and contextual factors (refer to Figure 2.4).

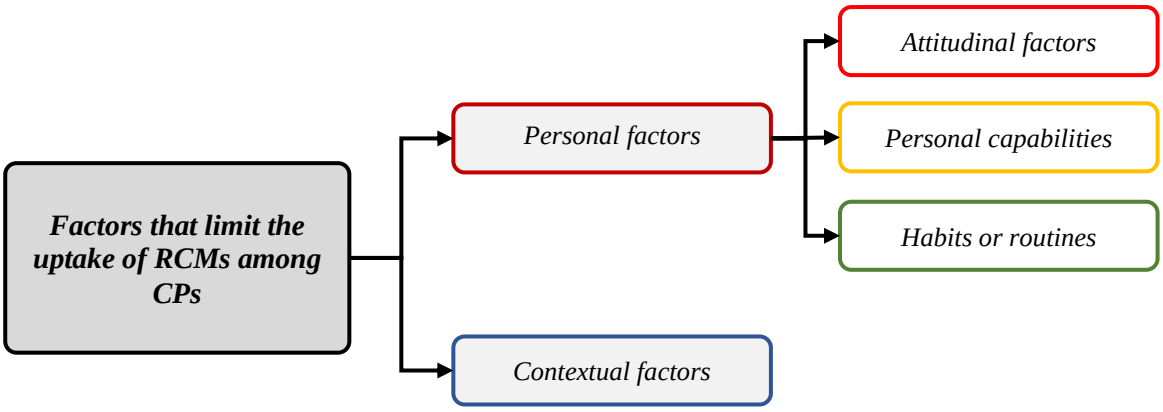


Figure 2.4: Classifying factors that limit the uptake of reprocessed construction materials among construction professionals based on Attitude-Behaviour-Context Theory

ABC Theory was selected for this study due to several reasons. Firstly, ABC Theory is highly appropriate for analysing pro-environmental behaviours since it originated in the domain of environmental studies (Guagnano, Stern & Dietz 1995). Secondly, unlike other behavioural theories that only focus on either personal or contextual factors that affect behaviour, ABC Theory provides a more thorough understanding of pro-environmental behaviours, which in reality, are determined by both personal and contextual factors (Guagnano, Stern & Dietz 1995; Stern 2000). While single-variable studies might showcase the explanatory power of a specific theoretical framework, they might not contribute substantially towards comprehensively understanding pro-environmental behaviours, which is necessary to induce change in such behaviours (Stern 2000). Thirdly, ABC Theory is grounded in more than thirty years of research and has been used in multiple studies to understand and explore pro-environmental behaviours and decision-making (Ertz, Karakas & Sarigöllü 2016; Okumah et al. 2020; Zhang, X & Dong 2020).

2.8.2.4 Exploring potential strategies for promoting the pro-environmental behaviour

The next step in the approach for promoting pro-environmental behaviours is to explore potential strategies for promoting the identified pro-environmental behaviour directly with representatives of the population whose behaviour is to be changed. Previous studies on pro-environmental behaviour have used two approaches to classify such strategies: (1) antecedent and consequence strategies and (2) informational and structural strategies (Abrahamse et al. 2005; Steg & Vlek 2009). According to the first approach, antecedent strategies influence pro-environmental behaviour before the behaviour is performed, while consequence strategies influence pro-environmental behaviour after the behaviour is performed by outlining a consequence that depends on the outcome of the specific

behaviour (Abrahamse et al. 2005). According to the second approach, informational strategies aim to change perceptions, motivations, and norms or, in other words, the attitudinal factors that limit pro-environmental behaviours, discussed in Section 2.8.2.3.1 (Klaniecki, Wuropulos & Hager 2016; Steg & Vlek 2009). In contrast, structural strategies primarily aim to change the circumstances under which behavioural choices are made, or in other words, the contextual factors that limit pro-environmental behaviours, discussed in Section 2.8.2.3.4 (Klaniecki, Wuropulos & Hager 2016; Steg & Vlek 2009). Considering these two approaches, the second approach, which classifies the strategies as informational and structural, was selected for this study since it aligns more closely with the classification of factors that limit pro-environmental behaviours discussed in Section 2.8.2.3. This follows the assertion that the strategies for changing specific behaviours must target the potential barriers to behavioural change (Abrahamse et al. 2005).

2.8.2.4.1 Informational strategies

Informational strategies focus on changing the attitudinal factors that limit pro-environmental behaviours. Previous studies have identified multiple informational strategies that can be used to promote pro-environmental behaviours. Based on a review of extant literature, Klaniecki, Wuropulos and Hager (2016) classified such informational strategies into five types: information and education, modelling, commitment, feedback, and goal setting, which are elaborated below.

One of the most commonly used informational strategies is providing *information and education* to increase the knowledge base for decision-making (Klaniecki, Wuropulos & Hager 2016; Rau, Nicolai & Stoll-Kleemann 2022). Information and education strategies aim to increase knowledge among actors about environmental problems and environmental impacts of their behaviours and/or pro-environmental behavioural alternatives available and their pros and cons (Steg & Vlek 2009). Prior research has shown that a higher level of knowledge can drive attitudinal change and henceforth affect pro-environmental behaviours (Mair & Bergin-Seers 2010; Steg & Vlek 2009; Vicente-Molina, Fernández-Sáinz & Izagirre-Olaizola 2013).

Modelling, which involves providing examples of recommended behaviours, was identified as another informational strategy that can be useful in promoting pro-environmental behaviours (Abrahamse et al. 2005; Michie, van Stralen & West 2011; Steg & Vlek 2009). Upon observing the behaviours of others, individuals can deduce what behaviours are expected from them in certain situations and use that as a benchmark for

their own behaviours (Rau, Nicolai & Stoll-Kleemann 2022). Prior research has also shown that asking individuals to *commit* to undertaking certain behaviours is an informational strategy that can induce positive changes in pro-environmental behaviour (Abrahamse et al. 2005; Klaniecki, Wuropulos & Hager 2016; Steg & Vlek 2009). Such commitments or pledges can be made either orally or in writing and can be made either privately or publicly (Rau, Nicolai & Stoll-Kleemann 2022). However, written and public commitments have been found to be more effective than oral and private commitments (Klaniecki, Wuropulos & Hager 2016).

Feedback, which involves providing individuals with insights about their performance and outcomes of specific tasks, has also been recognised as an informational strategy that can be used to encourage pro-environmental behaviours (Rau, Nicolai & Stoll-Kleemann 2022). Feedback influences behaviour by helping individuals understand the relationship between their performance of a specific task and achieving a specific outcome (e.g., the relationship between the use of an energy-efficient appliance and the energy savings achieved) (Abrahamse et al. 2005; Rau, Nicolai & Stoll-Kleemann 2022). *Goal setting* involves setting goals for future behaviour and is often used with commitment and feedback (Klaniecki, Wuropulos & Hager 2016). It provides a reference point for individuals to target their behaviours (e.g., reducing energy consumption by 5%) (Abrahamse et al. 2005). Apart from the above five types, several studies have also identified *credibility building*, where information is provided through trusted sources, as another effective informational strategy for promoting pro-environmental behaviours (Stern 1999, 2000). Credibility building aims to change behaviour by establishing trust with the target audience, thus increasing the likelihood of them acting upon the information being provided.

2.8.2.4.2 Structural strategies

Informational strategies can be less effective when strong contextual factors limit pro-environmental behaviours (e.g., high financial cost or inconvenience) (Stern 2000). In such circumstances, structural strategies must be used to address those contextual limitations. Klaniecki, Wuropulos and Hager (2016) and Steg and Vlek (2009) classified structural strategies as infrastructural, legislative, and policy strategies. *Infrastructural* strategies involve modifying physical, technical, and organisational systems to change the availability and viability of different pro-environmental behavioural alternatives or, in other words, making structural changes in the performance environment (e.g., providing recycling bins to facilitate recycling, making organic products readily available to drive

their use, installing energy-saving appliances to promote energy conservation) (Klaniecki, Wuropulos & Hager 2016; Rau, Nicolai & Stoll-Kleemann 2022; Steg & Vlek 2009; Verplanken & Wood 2006). *Legislative* strategies that include imposing legal regulations can also be considered in driving pro-environmental behaviours (Steg & Vlek 2009). As highlighted by the authors, an example of this strategy is banning harmful propellants in spray cans in the USA. *Policy* strategies have mainly been explained in relation to pricing policies that can be used to decrease the prices of pro-environmental behaviours and/or increase the prices of less environmentally friendly options, but other policy measures can also be explored (Rau, Nicolai & Stoll-Kleemann 2022; Steg & Vlek 2009). Recent studies have considered legislative and policy strategies under the common theme of policies (Rau, Nicolai & Stoll-Kleemann 2022).

Structural strategies are also needed to promote pro-environmental behaviours limited by undesirable habits (Klaniecki, Wuropulos & Hager 2016; Steg & Vlek 2009; Verplanken & Wood 2006). Prior studies have shown that habitual behaviours are immune to informational strategies (Mair & Bergin-Seers 2010; Verplanken & Wood 2006). According to habit literature, individuals who engage in a specific behaviour regularly tend to become less inclined to review or reassess that behaviour (Mair & Bergin-Seers 2010). They tend to concentrate on information that confirms their decisions while disregarding information that contradicts their established behaviours (Steg & Vlek 2009). Therefore, well-established habits cannot be easily altered by providing information. Consequently, altering the context within which the habitual behaviour occurs was identified as the most effective approach for influencing individuals towards desirable pro-environmental behaviours (Mair & Bergin-Seers 2010). Herein, Verplanken and Wood (2006) argued that economic measures such as taxes on undesirable behaviours and policy measures limiting undesirable behavioural alternatives could be potential strategies for disrupting undesirable habits. The authors further highlighted that structural strategies could be used to provide a stable context for creating and maintaining more desirable habits.

No specific category of strategies was identified that could be used to address the limitations associated with personal capabilities that may hinder pro-environmental behaviours. Herein, previous studies have acknowledged that either informational or structural strategies could be used contingent upon the specific limiting factor (Ertz, Karakas & Sarigöllü 2016). For instance, if the limiting factor is related to a lack of awareness, informational strategies can be used to address this limitation. Alternatively, if

the limiting factor revolves around financial capabilities, structural strategies such as favourable pricing policies could be considered.

Finally, most previous studies on pro-environmental behaviour suggest that using a single strategy is unlikely to change behaviour across the target population (Rau, Nicolai & Stoll-Kleemann 2022; Verplanken & Wood 2006). Therefore, a combination of strategies would have to be used by considering the factors limiting the desired behaviour (e.g., information to increase awareness and drive engagement, education and training to self-empower individuals to change behaviour and feedback to enhance commitment) (Rau, Nicolai & Stoll-Kleemann 2022). When both attitudinal and contextual factors limit pro-environmental behaviours, combining multiple strategies has been found to result in the most impact (Klaniecki, Wuropulos & Hager 2016). Moreover, studies have also shown that such strategies are most effective when designed from the perspective of actors whose behaviour must be changed (Stern 1999, 2000). This is because they are the ones best placed to comment on the chief obstacles to behavioural change.

Insights from this review on the strategies for promoting pro-environmental behaviours were used in the current study to identify and classify potential strategies for promoting the uptake of RCMs among CPs. Figure 2.5 depicts the classification of the strategies identified.

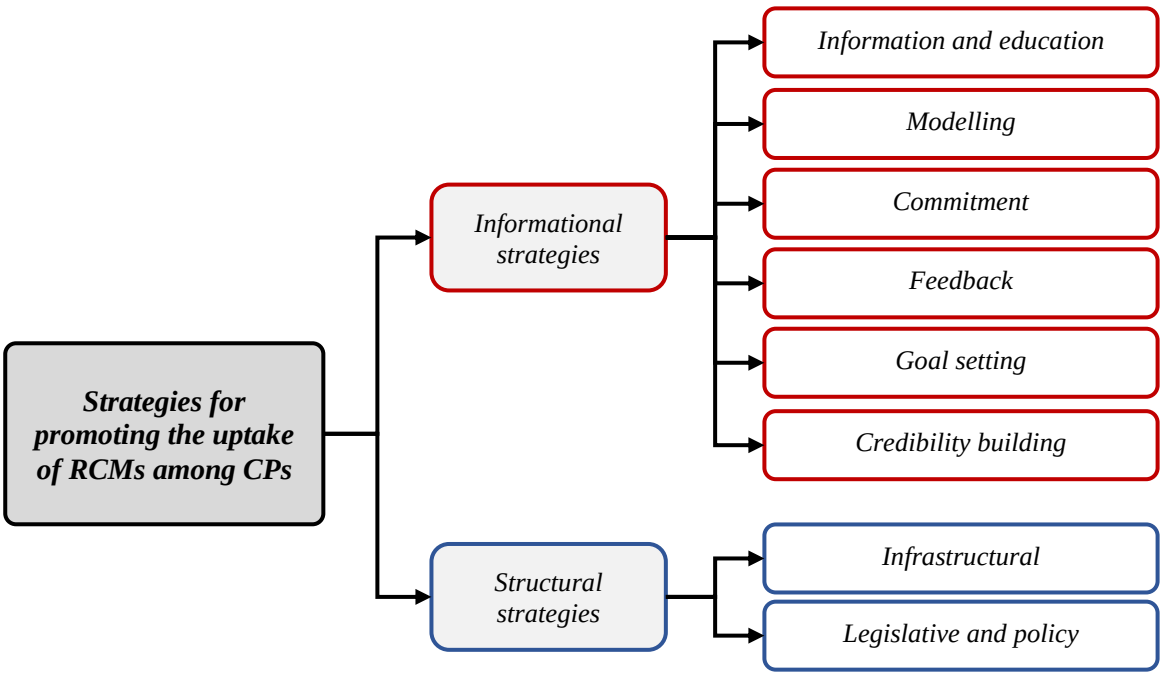


Figure 2.5: Classifying the strategies for promoting the uptake of reprocessed construction materials among construction professionals

2.8.2.5 Applying and evaluating the effectiveness of the strategies

Upon exploring potential strategies for promoting a specific pro-environmental behaviour, the next step is to apply and evaluate the effectiveness of the strategies identified. Once applied, the systematic evaluation of the strategies offers insights not only into the degree to which a specific strategy has been successful in promoting the expected pro-environmental behaviour and minimising the environmental impact but also highlights the reasons behind its (un)success and offers suggestions on how the strategy might be adjusted to enhance its efficacy (Steg & Vlek 2009). Such an evaluation is essential from a practical viewpoint since it can inform the change agents of any need to refine or replace a specific strategy (McKenzie-Mohr & Schultz 2014; Steg & Vlek 2009). Before applying the strategies on a broad scale, they can be pilot-tested to evaluate their efficacy in changing pro-environmental behaviours and their cost-effectiveness (McKenzie-Mohr & Schultz 2014). Once the effectiveness of a strategy is affirmed through pilot testing, it can be implemented on a broader scale. The current study was limited to exploring the potential strategies for promoting the uptake of RCMs. The strategies identified could not be applied and evaluated in this study since it often requires experimental research designs, which are costly and time-consuming to execute (Abrahamse et al. 2005; Steg & Vlek 2009) and was therefore not feasible within the scope, funding and timing constraints of the study. Figure 2.6 relates the approach for promoting pro-environmental behaviours identified through the literature review with the current study. As indicated in the figure, the first and second objectives of the study (refer to Section 1.4), were developed based on the third and fourth steps of this approach for promoting pro-environmental behaviours.

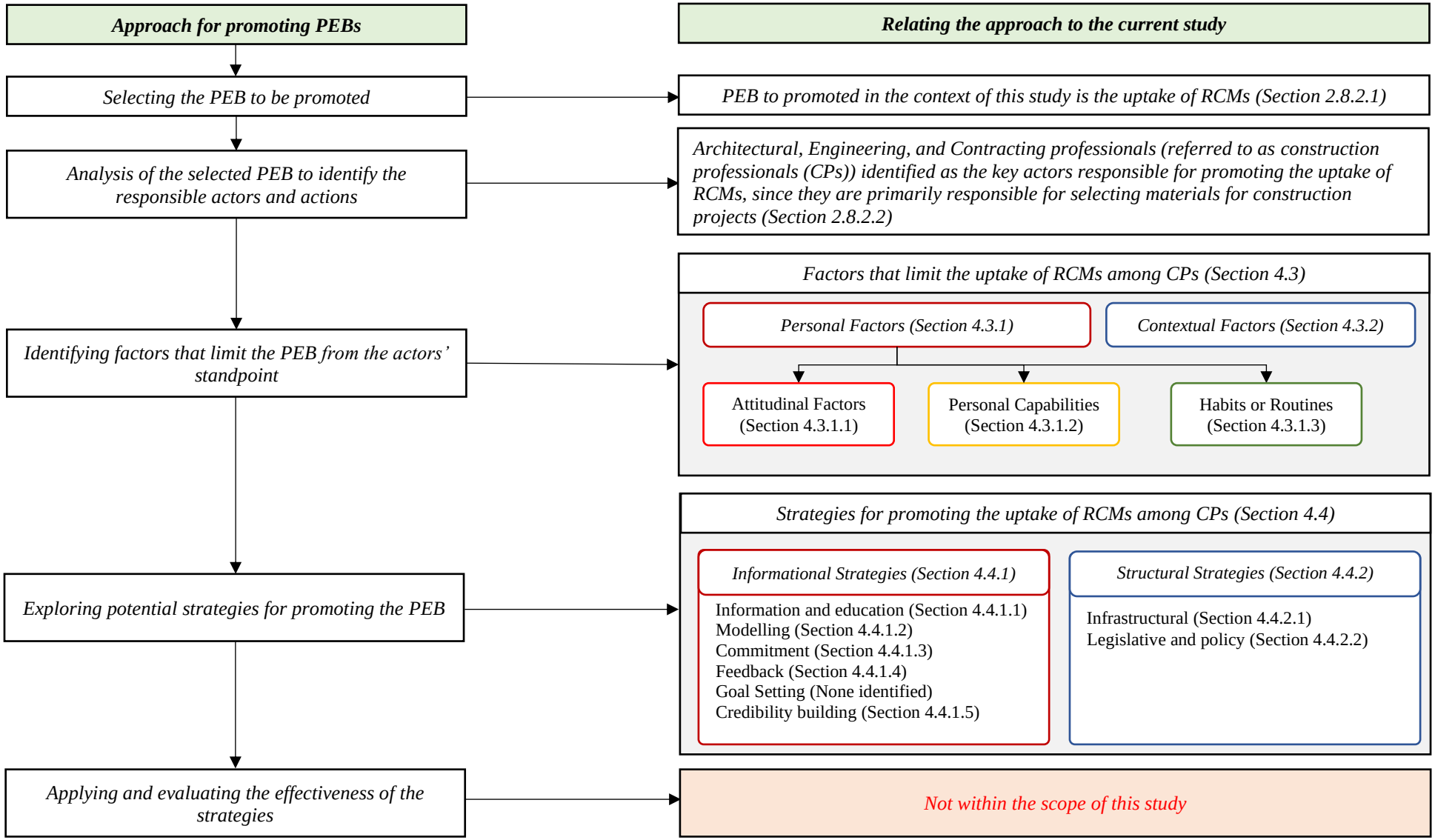


Figure 2.6: Relating the approach for promoting pro-environmental behaviours (PEBs) to the current study

2.9 Structuring waste recovery processes to meet the requirements of the end users of reprocessed materials

Occupying a central position within RLSCs, waste processors play a crucial role by obtaining waste from waste generators and converting that waste into reprocessed materials, which are then sold and distributed to end users in the secondary market. Given that waste processors depend on end users for procuring their reprocessed materials, RL literature has emphasised the importance of waste processors structuring their processes in a user-centric manner to align with the requirements of end users. Research studies indicate that adopting such a user-centric approach would result in improved user satisfaction and, consequently, a higher uptake of reprocessed materials. Therefore, it can be argued that waste processors can promote the uptake of reprocessed materials by adopting a more user-centric approach to structuring their processes, which applies in the context of RLSCs for DW as well. Consequently, this section reviewed the current literature on user-centric RL and its relevance to RLSCs for DW.

2.9.1 User-centric reverse logistics

Traditionally, organisations prioritised improving process efficiencies without placing much emphasis on understanding the requirements of end users (Frank et al. 2020; Kreuzer, Röglinger & Rupprecht 2020). However, the authors noted that there has been a shift in this approach, with many organisations now rethinking and redesigning their business processes to align with the needs of end users. In other words, organisations have become more user-centric. User-centricity has emerged as a crucial determinant of the success of many organisations, necessitating business processes to be aligned with the requirements of end users (Frank et al. 2020). Studies have shown that organisations prioritising user-centric approaches have benefitted from enhanced user satisfaction, loyalty, and retention, resulting in overall market success (Inversini, De Carlo & Masiero 2020; Lee et al. 2014). Conversely, organisations that have failed to be user-centric run the risk of losing market share. Consequently, multiple studies have stressed the importance of organisations transitioning from an inside-out perspective to an outside-in perspective when developing their processes (Frank et al. 2020; Rosemann 2014).

This increased recognition of the significance of placing user-centricity as a priority within forward logistics has led to a corresponding increase in recognition of adopting user-centric approaches in RL as well (Ahmadi et al. 2022; Shokouhyar, Dehkhodaei & Amiri 2022). In one of the seminal studies on RL, Carter, CR and Ellram (1998) analysed the

external factors that can impact the RL processes of waste processors. The study highlighted customers, i.e., the end users of reprocessed materials, as a formidable force that influences RL processes since waste processors depend on end users to procure their materials. Therefore, the authors contended that aligning RL processes with end-user requirements would enable waste processors to respond to the market requirements appropriately and achieve superior market performance. Likewise, Dowlatshahi (2000) identified end users as an external force that drives RL systems depending on who they are, their needs, and their inclination to support RL, and RL systems must, as a result, strive to meet the needs of end users.

Genchev (2009) expressed that it is vital for waste processors to obtain the input of the end users of reprocessed materials in developing RL processes since it highlights user concerns that might have to be addressed by them ahead of implementing a RL system. According to the author, such a proactive approach would be useful to avert any potential problems before they materialise, thus adequately meeting the requirements of end users. Following a similar line of thought, Shaik and Abdul-Kader (2014) noted the need for waste processors to assess the expectations of end users in fostering harmonious development between RL processes and specific user requirements. Furthermore, Govindan and Bouzon (2018) reiterated that RL decisions based on the opinions or sentiments of end users could increase the competitive potential of waste processors. These studies collectively underscore the importance of waste processors adopting a user-centric approach, whereby the requirements of the end users of reprocessed materials are considered in structuring their processes.

Waste processors can achieve numerous benefits by following such a user-centric approach when structuring their processes. Among these benefits, user satisfaction emerges as a key outcome, as acknowledged in multiple studies (Agrawal, Singh & Murtaza 2016; Ahmadi et al. 2022; Shokouhyar, Dehkhodaei & Amiri 2022). Shokouhyar, Dehkhodaei and Amiri (2022) specifically highlighted the significance of achieving user satisfaction since it serves as a precursor for increased transactions and user retention, ultimately contributing to the overall success of a firm. This has been supported by further studies which have demonstrated that user satisfaction can yield benefits to waste processors, such as an increase in the uptake of reprocessed materials, repeat orders from end users, enhanced long-term profitability and a strengthened competitive advantage (Ahmadi et al. 2022; Govindan & Bouzon 2018; Shaik & Abdul-Kader 2014).

In structuring their processes to be user-centric, Dowlatshahi (2000) highlighted that waste processors need to identify and address features that end users expect from reprocessed materials, which can include aspects such as quality, reliability, and efficient delivery. For instance, the authors highlighted that end users would anticipate reprocessed materials to possess comparable and uniform quality as their virgin counterparts. They would also require such materials to be conveniently accessible in terms of timing, location, and quantity while being offered at appropriate prices. The author further mentioned that waste processors need to consider educating end users, or in other words, marketing reprocessed materials, as part of the user-centric approach. Similar ideas have also been conveyed by Carter, CR and Ellram (1998). In relation to identifying and addressing anticipated features, the authors posited that if waste processors can provide reprocessed materials of high quality and consistency, the likelihood of end users procuring such materials will increase. The authors also acknowledged the importance of improving marketing efforts and maintaining closer relationships with end users to enhance the acceptance of reprocessed materials.

The literature highlighted above emphasises that waste processors must follow a user-centric approach when structuring their processes. Herein, waste processors must first identify the requirements expected by end users of reprocessed materials from such materials and structure their processes accordingly to meet those requirements. By adopting such a user-centric approach, waste processors can achieve higher user satisfaction, resulting in the improved uptake of reprocessed materials, better profitability, and a stronger competitive advantage.

2.9.2 User-centricity in reverse logistics supply chains for demolition waste

As with all RLSCs, waste processors play a crucial role in RLSCs for DW by converting DW into RCMs that can be used in new construction applications. As depicted in Figure 2.7, waste processors occupy a central position within RLSCs for DW. They establish connections with demolition contractors, who generate DW, as well as the end users in the secondary market, who use RCMs. Waste processors receive DW from demolition contractors, reprocess it into RCMs, and distribute it to end users. Essentially, the majority of the processes involved in transforming DW into RCMs are carried out by waste processors, and the success of their efforts relies heavily on the uptake of RCMs by end users. Consequently, in line with existing literature on user-centric RL, multiple studies have recognised that waste processors in RLSCs for DW must also structure their processes in a user-centric manner to meet the requirements of the end users of RCMs,

who, in this context, are the CPs involved in selecting materials for construction projects (explained in Section 2.8.2.2).

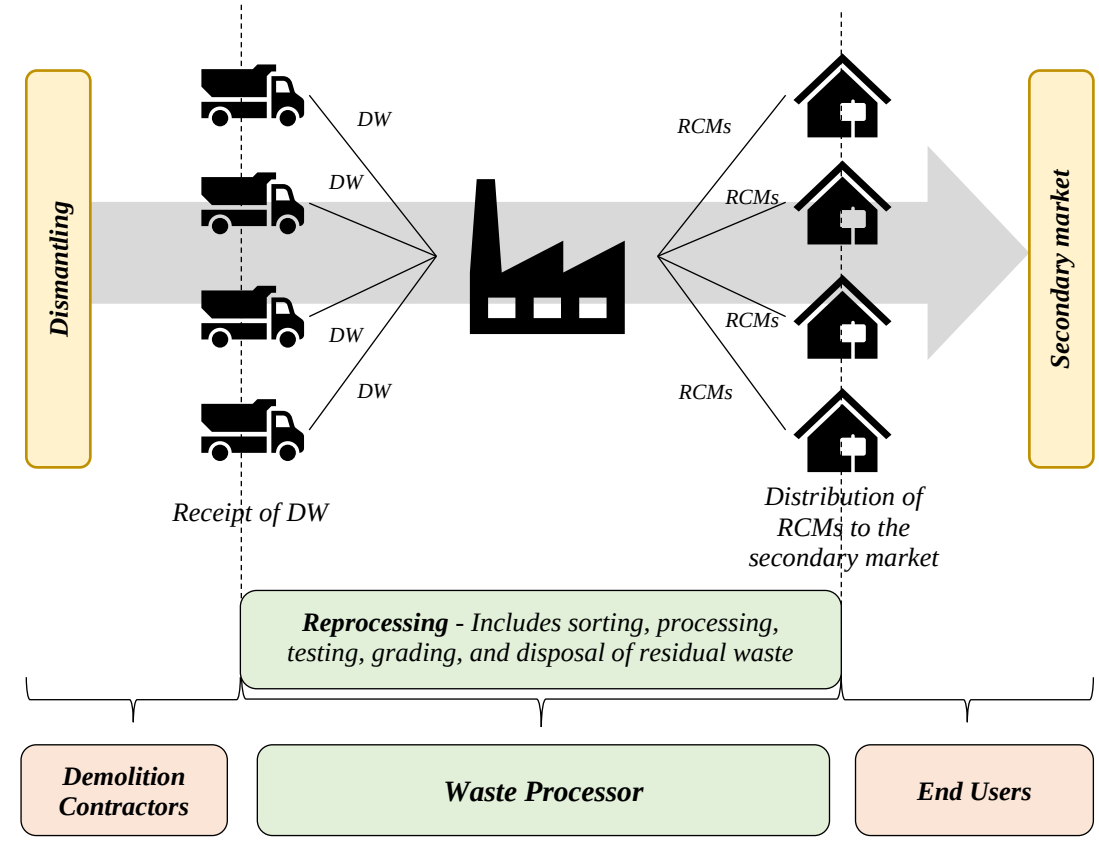


Figure 2.7: Role of waste processors in reverse logistics supply chains for demolition waste

Supporting the need for user-centricity, Yeheyis et al. (2013) acknowledged that the economic feasibility of reprocessing DW depends on the ability of waste processors to condition RCMs according to market requirements. Following a similar line of thought, Jayasinghe, Chileshe and Rameezdeen (2019) highlighted that upstream DW recovery processes must be oriented towards meeting the requirements of downstream markets for RCMs. A subsequent study conducted by the same authors recognised the dissatisfaction of users with RCMs as one of the key risks affecting the operational performance of waste processors, which in turn underscores the need for waste processors to consider end-user requirements when structuring their processes (Jayasinghe, Rameezdeen & Chileshe 2022). Likewise, Liu et al. (2020) acknowledged that waste processors need to communicate more with end users of RCMs to understand their interests and subsequently develop new operating models that can be beneficial for achieving market success. A recent study by

Tennakoon, Rameezdeen and Chileshe (2022b) further concluded that the success of DW recovery efforts depends directly upon the demand for RCMs and waste processors must, therefore, act proactively to understand the requirements of end users and structure their processes accordingly. Moreover, Tennakoon, Rameezdeen and Chileshe (2022a) showed that by structuring their processes to cater to the requirements of end users, waste processors could effectively contribute towards promoting the uptake of RCMs.

Despite previous studies acknowledging the importance of waste processors structuring their processes in a user-centric manner, systematic literature reviews specifically focusing on RLSCs for DW revealed a dearth of research in this area (Jayasinghe, Rameezdeen & Chileshe 2019; Tennakoon, Rameezdeen & Chileshe 2022b, 2022a). This aligns with the assertions of Ahmadi et al. (2022) and Shokouhyar, Dehkhodaei and Amiri (2022) regarding the scarcity of research available on user-centric RL. Consequently, there is a need for further studies to identify the requirements expected by the end users of RCMs from the waste processors and to understand the measures that waste processes could take to structure the DW recovery processes to meet such requirements effectively.

2.10 Knowledge gaps

The management of increasing amounts of DW and the scarcity of natural resources present significant challenges for the construction industry (Chileshe, Jayasinghe & Rameezdeen 2019; Pickin et al. 2020; Purchase et al. 2022; Silva, de Brito & Dhir 2017; Soonsawad, Martinez & Schandl 2022). In response, the construction industry has embraced the concept of RL, which involves the conversion of DW into RCMs that can be used in new construction applications. This encompasses a series of processes, including dismantling, reprocessing, secondary market operations, and residue disposal, collectively known as RLSCs for DW (Jayasinghe, Rameezdeen & Chileshe 2022). By following these stages, DW can be transformed into RCMs, thereby reducing the amount of waste sent to landfills and decreasing the demand for virgin materials.

Previous research has demonstrated that the success of RLSCs for DW relies heavily on the market uptake of RCMs (Ding, Nie & Wu 2022; Silva, de Brito & Dhir 2017; Yu et al. 2021). These studies emphasised that neglecting the consumption or market aspect of RL would undermine the long-term viability of RLSCs for DW. Despite this, the literature review revealed a limited uptake of RCMs in many countries, including Australia (Chileshe et al. 2015; Jin et al. 2017; Oyedele, Ajayi & Kadiri 2014; Park & Tucker 2017; Schut, Crielaard & Mesman 2015; Shooshtarian et al. 2020b). Herein, Chileshe et al.

(2015) expressed concerns over the lack of demand for RCMs, which has hindered the success of RL in the Australian construction industry. Similarly, Shooshtarian et al. (2020b) concluded that despite ongoing efforts to develop markets for RCMs, their performance remains suboptimal. These findings underscore the imminent need to promote the uptake of RCMs. However, a lack of research exists regarding promoting the uptake of RCMs among end users, including within the Australian context (Shooshtarian et al. 2022a; Shooshtarian et al. 2020b; Tennakoon, Rameezdeen & Chileshe 2023). The current study aimed to address this knowledge gap by exploring the uptake of RCMs from the perspective of CPs. CPs were focused on in this study since the literature review showed that they are the key actors involved in selecting materials for construction projects (Oyedele, Ajayi & Kadiri 2014; Shooshtarian et al. 2020a). Further, it was revealed that a pro-environmental behaviour perspective could be adopted here, wherein the uptake of RCMs is viewed as a pro-environmental behaviour to be adopted by CPs. Previous research on pro-environmental behaviours outlined a five-step process for promoting such behaviours, and this process was adopted for this study, as explained in Section 2.8.2.

Whilst highlighting the importance of promoting the uptake of RCMs, the literature review affirmed the importance of waste processors structuring DW recovery processes in a user-centric manner (Jayasinghe, Chileshe & Rameezdeen 2019; Liu et al. 2020; Tennakoon, Rameezdeen & Chileshe 2022b; Yeheyis et al. 2013). This entails waste processors identifying the requirements expected by the end users of RCMs for incorporating such materials into construction projects and structuring their processes to meet those requirements (Ahmadi et al. 2022; Dowlatshahi 2000; Shokouhyar, Dehkhodaei & Amiri 2022). By adopting such a user-centric approach, waste processors can enhance user satisfaction, thereby promoting the uptake of RCMs (Ahmadi et al. 2022; Shokouhyar, Dehkhodaei & Amiri 2022; Tennakoon, Rameezdeen & Chileshe 2022a). Despite the importance of waste processors structuring their processes in a user-centric manner being acknowledged, recent studies have revealed a scarcity of research in this area, thus indicating a knowledge gap (Jayasinghe, Rameezdeen & Chileshe 2019; Tennakoon, Rameezdeen & Chileshe 2022b, 2022a). The current study, therefore, attempted to address this knowledge gap through an extensive investigation into how waste processors can structure DW recovery processes in a user-centric manner to meet the requirements of CPs, who were recognised as the key end users of RCMs. Figure 2.8 shows the identified knowledge gaps and the associated research questions, matched with the main target groups of the study.

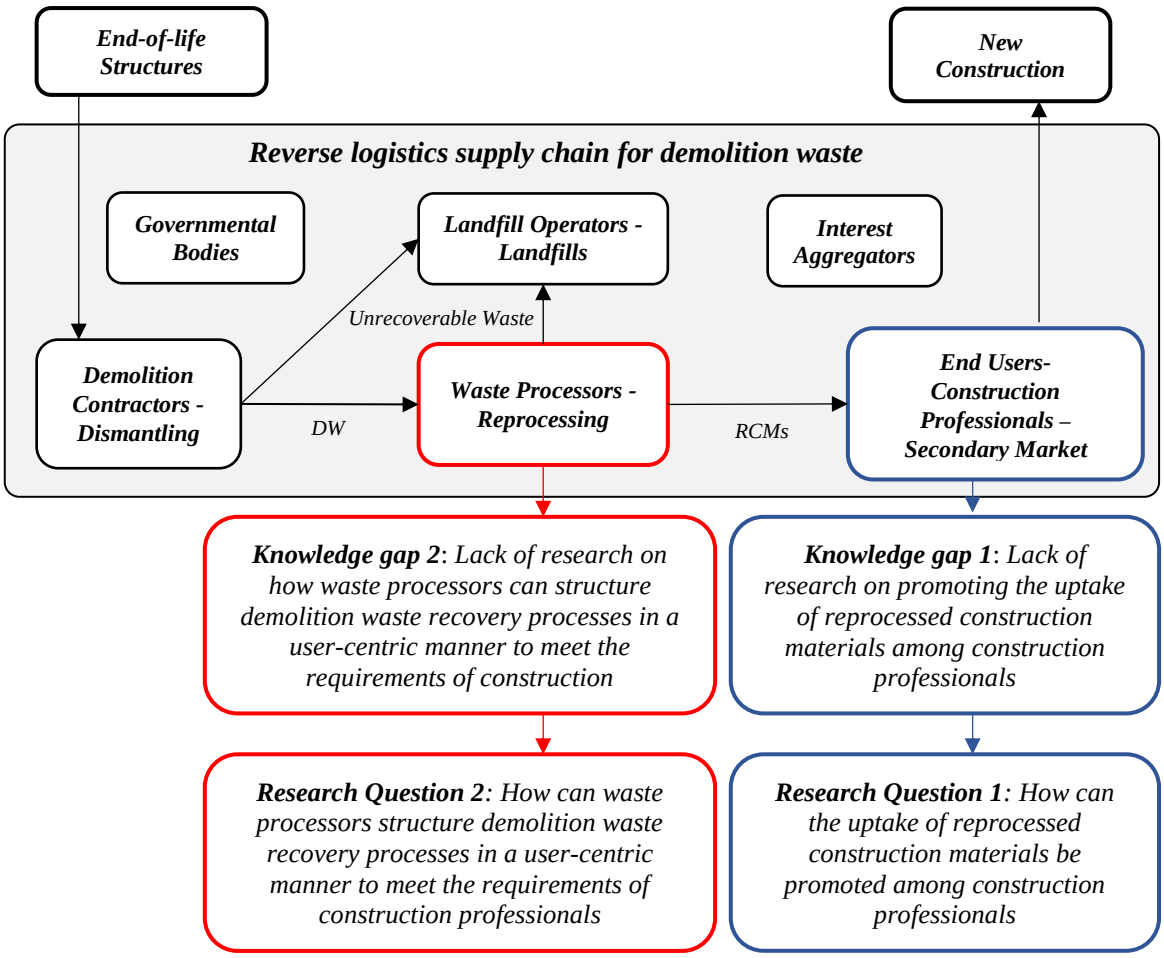


Figure 2.8: Knowledge gaps and associated research questions

2.11 Chapter summary

This chapter presented an in-depth literature review of the key areas of focus of the current study. Firstly, an introduction to the concepts of RL and RLSCs for DW was presented, outlining the stages of RLSCs for DW and the stakeholders involved. Then, the significance of the market uptake of RCMs in ensuring the success of RLSCs for DW was highlighted, followed by an emphasis on the problem of the low uptake of RCMs in both the global and Australian contexts. The chapter then explored the uptake of RCMs from a perspective of pro-environmental behaviour, examining approaches to promote such behaviours among CPs. Further, the literature on user-centric RL was reviewed, highlighting its relevance to RLSCs for DW and emphasising the need for waste processors to structure DW processes in a user-centric manner to meet the requirements of CPs. Finally, the knowledge gaps identified through the literature were presented, which serve as the main areas of focus for the study. The next chapter presents the methodology adopted in conducting the empirical study.

CHAPTER THREE: METHODOLOGY

3.1 Introduction

Chapter 2 presented a literature review regarding the key concepts related to this study and established the knowledge gaps expected to be addressed. This chapter presents the research methodology adopted for this study and includes a discussion regarding the philosophical position of the study, the research approaches followed, and the research techniques used for data collection and analysis. Aspects related to ensuring the trustworthiness of research findings and ethical considerations are also discussed towards the end of the chapter.

3.2 Methodological framework

According to Fellows and Liu (2015), research is a well-coordinated activity that seeks to contribute new knowledge to the existing body of knowledge. Such a process for creating new knowledge is expected to follow a systematic or structured method of inquiry (Collis & Hussey 2014). In this context, different authors have proposed distinct methodological frameworks that outline procedures for facilitating a process of systematic inquiry. Among these frameworks, the nested model proposed by Kagioglou et al. (2000) was identified by previous studies as a popular methodological framework used in built-environment-related research (Alankarage et al. 2023; Omotayo & Kulatunga 2015; Pathirage, Amaratunga & Haigh 2006; Sridarran 2018; Wimalaratne & Kulatunga 2022). This model comprises three layers, namely research philosophy, research approach and research techniques, as shown in Figure 3.1.

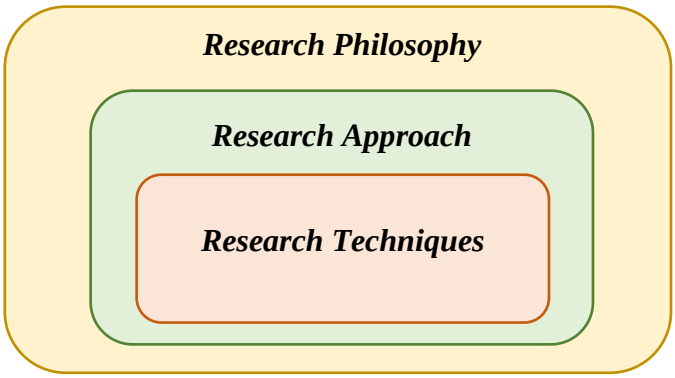


Figure 3.1: The nested model (Source: Kagioglou et al. 2000)

The research philosophy elucidates the underlying assumptions of the researcher, the research approaches consist of the dominant theory building and testing methods, and the research techniques represent the tools used for data collection and analysis (Kagioglou et al. 2000). According to this framework, the research philosophy, which is the outer-most layer, guides and energises the selection of the inner research approaches and research techniques (Kagioglou et al. 2000). The ensuing sections elaborate in detail the research philosophy, research approaches, and research techniques adopted for this research.

3.3 Research philosophy

The research philosophy refers to a system of beliefs and assumptions of a researcher regarding the development of knowledge, which underpins the selection of the appropriate research approaches and techniques (Kagioglou et al. 2000; Saunders, Lewis & Thornhill 2019). It reflects the researcher's perspectives regarding the relationship between knowledge and the process adopted to create that knowledge. These philosophical assumptions are primarily threefold: ontological, epistemological, and axiological (Collis & Hussey 2014; Saunders, Lewis & Thornhill 2019). These threefold assumptions lie along a multidimensional and integrated set of continua (Niglas 2010). Consequently, different combinations of these assumptions along the set of continua determine the philosophical position of a researcher.

Ontology refers to the assumptions regarding the nature of reality (Collis & Hussey 2014; Saunders, Lewis & Thornhill 2019). The two extremes of ontological positions can be characterised as objectivism and subjectivism/constructivism (Collis & Hussey 2014; Sutrisna 2009). Objectivism asserts that reality exists independent of the social actors. Alternatively, subjectivism asserts that reality does not exist independent of social actors and is constructed through the perceptions and the consequent actions of these actors. Therefore, objectivism believes that there is only one objective reality experienced by

everyone, whilst subjectivism believes in multiple realities constructed by each individual differently (Sutrisna 2009). Epistemology refers to the assumptions about what constitutes valid knowledge and how knowledge is acquired and accepted (Collis & Hussey 2014; Saunders, Lewis & Thornhill 2019). At the objective extreme, it is believed that knowledge comes from the objective measurement of a phenomenon, while at the subjective extreme, it is believed that knowledge comes from subjective evidence from participants acquired with thick descriptions and narrations (Collis & Hussey 2014; Saunders, Lewis & Thornhill 2019). Axiology refers to how much value is placed by the researcher on the research (Collis & Hussey 2014; Saunders, Lewis & Thornhill 2019). The value placed by the researcher increases when moving from the objective extreme to the subjective extreme along the continua. Research is considered to be value-free at the objective extreme and value-laden at the subjective extreme.

Based on the above philosophical assumptions, two main philosophical positions have been developed: positivism and interpretivism (Collis & Hussey 2014). Positivism is characterised by the ontological assumption that reality is singular, external, objective, and pre-determined. It holds the epistemological assumption that knowledge should come from observable and measurable phenomena. Axiologically, positivism believes that researchers should maintain a value-free stance, detach themselves from the research environment, and act as independent observers, thereby not allowing their values to distort research results. Further, positivist research seeks causal explanations and predictions and law-like generalisations and follows a deductive approach to research (Collis & Hussey 2014; Saunders, Lewis & Thornhill 2019). Since positivism assumes that social phenomena can be measured, it is associated with quantitative analysis methods based on the analysis of quantitative research data (Collis & Hussey 2014; Saunders, Lewis & Thornhill 2019). Alternatively, interpretivism (also referred to as social constructivism) is characterised by the ontological assumption that reality is subjective, socially constructed, and multiple. Therefore, epistemologically, interpretivism assumes that knowledge is created subjectively through qualitative means by examining people's perceptions. Unlike positivism, which seeks causal explanations or law-like generalisations, interpretivism values the different perspectives of people regarding their experiences (Saunders, Lewis & Thornhill 2019). This encourages the researcher to maintain close interactions with the research environment, and therefore, interpretivism maintains the axiological assumption that research is subjective and value-laden (Collis & Hussey 2014; Saunders, Lewis &

Thornhill 2019). Table 3.1 summarises the philosophical assumptions that underpin positivism and interpretivism.

Table 3.1: Philosophical assumptions that underpin positivism and interpretivism (Adapted from Collis and Hussey 2014)

Assumption	Positivism	Interpretivism
Ontological assumption (*the nature of reality*)	Reality is objective and external to the researcher	Reality is subjective and socially constructed
	There is only one reality	There are multiple realities
Epistemological assumption (*what constitutes valid knowledge and how knowledge is acquired and accepted*)	Knowledge comes from objective evidence about observable and measurable phenomena	Knowledge comes from subjective evidence from participants
	The researcher is distant from the phenomena under study	The researcher interacts with phenomena under study
Axiological assumption (*the role of values*)	The researcher is independent from phenomena under study	The researcher acknowledges that the research is subjective
	The results are unbiased and value-free	The findings are biased and value-laden

In light of the research questions posed, it can be argued that this research leans more towards the philosophical position of interpretivism. Initially, the research focused on investigating the uptake of reprocessed construction materials (RCMs) among construction professionals (CPs) in order to understand how the uptake of such materials can be promoted. As supported by extant literature, the uptake of RCMs is a complex social phenomenon, which can be limited by personal factors such as attitudes, personal capabilities, and habits of individual CPs as well as external contextual factors related to the broader context within which they operate. Therefore, it can be reasonably argued that there is no singular optimal approach for promoting the uptake of RCMs and that the strategies that could be used can vary based on the nature of individual CPs and the broader context within which they operate. This recognition of diverse perspectives indicates a resonance with interpretivism principles. Furthermore, the study seeks to understand how waste processors can structure demolition waste (DW) recovery processes in a user-centric manner to meet the requirements of CPs. Herein, the ability to structure DW recovery processes can vary among different waste processors based on their internal resources and capabilities as well as contextual factors such as location, resource availability, and regulatory frameworks. Additionally, the requirements expected by CPs from the waste processors can also be subjective and context-dependent. Consequently, the study acknowledges the existence of multiple realities and embraces the idea that reality is subjective and socially constructed, thus aligning with ontological assumptions of

interpretivism. The study embraces the epistemological assumption that knowledge is created subjectively through qualitative means by examining the perceptions of people, which follows the philosophical stance of interpretivism. The study values and promotes the free flow of knowledge and insights of people based on their experiences with using RCMs and managing DW recovery processes, recognising human interaction as the main driver of knowledge. Exploring multiple realities through subjective means of knowledge creation necessitates close interactions between the researcher and the research participants. Consequently, the researcher becomes intricately connected with the phenomenon under investigation. Therefore, it is assumed that the research is inherently biased and value-laden and is shaped by the researcher's values, thus aligning with the value-laden axiological assumptions of interpretivism.

3.4 Research approaches

Certain research approaches align more closely with a specific research philosophy than others, and the selection of appropriate research approaches must therefore reflect the philosophical position of the research (Kagioglou et al. 2000). Considering the philosophical position of this research, which leans more towards interpretivism, qualitative research approaches that allow for subjective means of knowledge creation should ideally be selected (Sutrisna 2009). A multitude of qualitative research approaches can be identified through extant literature, which primarily includes narrative inquiry, grounded theory, action research, ethnography, case studies and qualitative surveys (Jansen 2010; Saunders, Lewis & Thornhill 2019; Wimalaratne & Kulatunga 2022). Herein, both qualitative surveys and case studies were selected as suitable approaches for this study to address specific research questions. This study comprised of two phases. The first phase of the study followed a qualitative survey approach to address the first research question: “How can the uptake of RCMs be promoted among CPs?” Following on from the first phase, the second phase of the study adopted a case study approach to address the second research question: “How can waste processors structure DW recovery processes in a user-centric manner to meet the requirements of CPs?” The following sections will discuss in further detail the choice of the two research approaches in relation to this study.

3.4.1 Phase I – Qualitative survey

Qualitative surveys are being increasingly recognised as a distinct approach to qualitative research (Jansen 2010; Mbanaso, Abrahams & Okafor 2023; McIntosh, S, Woods & Stother 2022; Merriam & Tisdell 2016; Wimalaratne & Kulatunga 2022). Traditionally,

the term “survey” was associated with quantitative research, which sought to describe numerical distributions of variables within a specific population (Fraenkel, Wallen & Hyun 2012; Jansen 2010). However, the qualitative survey takes a different approach, aiming to explore the diversity of a topic of interest within a given population rather than establishing frequencies, means or other parameters that are characteristic of quantitative surveys (Jansen 2010). Essentially, a qualitative survey is the study of diversity or meaningful variation within a population (Jansen 2010). Qualitative surveys have also been referred to as basic qualitative research in extant literature (Merriam & Tisdell 2016).

Qualitative surveys are primarily used to explore the meanings people attach to their experiences and how they express themselves (Fink 2003). Qualitative surveys are particularly suited for exploring the knowledge, opinions, feelings, and values of individuals and groups, such as experts in specific domains or those who have shared similar experiences (Fink 2003; Wimalaratne & Kulatunga 2022). Further, qualitative surveys prove valuable when researchers seek to understand the views of participants as expressed in their own words (Fink 2003; Jansen 2010). They are also useful when existing literature provides limited support or when access is available only to a small group of participants (Fink 2003; Wimalaratne & Kulatunga 2022). Moreover, qualitative surveys have been used in previous studies with specific target groups such as substance abusers, street people, disadvantaged individuals, and those who are very young or are mentally or terminally ill and are therefore unlikely or unable to participate in traditional surveys (Davey, Clarke & Jenkinson 2019; Fink 2003; Jansen 2010; McIntosh, S, Woods & Stother 2022; Verger et al. 2018).

In line with the aforementioned uses of the qualitative survey approach, it was selected for Phase I of this study to address the first research question, which necessitated identifying potential factors that limit the uptake of RCMs among CPs and exploring potential strategies for promoting the uptake of such materials. This required an in-depth exploration of the knowledge and experiences of CPs regarding the uptake of RCMs. Herein, the qualitative survey approach was considered suitable since it can be used to effectively capture the knowledge and experiences of research participants in their own words, as explained above. Furthermore, the research area on the uptake of RCMs, particularly in the Australian context, has been relatively understudied, as evident from the literature review. Additionally, the limited number of potential participants with prior experience in using RCMs posed a challenge in accessing large samples of participants. Given these circumstances, the choice of the qualitative survey approach was justified, as it is well-

suited for situations where there is limited support from existing literature and access to research participants is limited. In summary, the decision to employ a qualitative survey approach in this study is well founded, as it allowed for a thorough investigation of the perspectives of CPs regarding the uptake of RCMs, an area that has received limited attention in the existing literature and is challenging to access large numbers of participants.

3.4.2 Phase II – Case studies

Yin (2018, p. 10) defined case studies as an approach to empirical inquiry that "*investigates a contemporary phenomenon in depth and within its real-world context, especially when the boundaries between phenomenon and context may not be clearly evident*." As highlighted through the definition, case studies can be used to develop in-depth insights about cases within a real-world setting, and these cases can often include one or more individuals, organisations, processes, programs, activities or events (Creswell & Creswell 2018; Yin 2018).

According to Yin (2018), the case study approach can be used when the research question is of the form of "how" or "why", and the researcher has no control over actual behavioural events and where the focus of the research is on contemporary events. In the current research, case studies were used to address the second research question: "How can waste processors structure DW recovery processes in a user-centric manner to meet the requirements of CPs?" In this research, the researcher acted as an external observer, maintaining no influence or control over the events that took place in the environment studied. Further, the focus of the research was on understanding current DW recovery processes, underscoring the contemporary nature of the study. Consequently, the current research conforms to all three specified conditions for employing a case study approach, thereby substantiating the rationale behind its adoption for this research. Furthermore, addressing the research question posed necessitated an in-depth investigation into the DW recovery processes employed by waste processors. This was facilitated by case studies, which allow for in-depth and intensive investigations regarding specific topics or phenomena of interest (Merriam & Tisdell 2016; Yin 2018). Moreover, the case study approach allows for a variety of data sources to be used, such as interviews, observations, and documents (Yin 2018), which is considered a strength of this approach. This enhances the richness of data and enables data triangulation, thereby reinforcing the validity and robustness of the findings (Alankarage et al. 2023; Edwards & Holt 2010). All these reasons led to the selection of the case study approach for Phase II of the study.

3.4.2.1 Design of case studies

The "case" considered under a case study can refer to processes, individuals, groups of individuals, organisations, associations, events and many other types of case subjects (Saunders, Lewis & Thornhill 2019; Yin 2018). A key consideration in carrying out case studies involves determining the number of cases and the unit of analysis. Yin (2018) identified four (4) types of case study designs based on the number of cases and the unit of analysis. Based on the number of cases, case study designs were first divided into two (2) single-case designs and multiple-case designs and each of these was further divided into two (2) based on the unit of analysis, as holistic and embedded. If a single unit of analysis is used within a case, it is referred to as a holistic design, and if multiple units of analysis are used within a case, it is referred to as an embedded design. Figure 3.2 shows the case study design types adapted from Yin (2018).

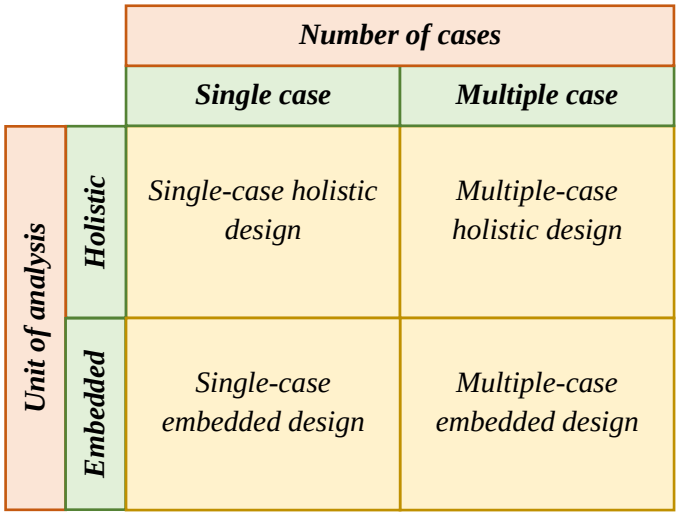


Figure 3.2: Basic case study design types (Adapted from Yin (2018))

3.4.2.1.1 Selecting the unit of analysis

The unit of analysis refers to the primary unit that will be subjected to analysis within a case and is the central point to which the research problem, phenomena and variables refer and for which data is collected and analysed (Alankarage et al. 2023; Collis & Hussey 2014). In the context of a case study, the unit of analysis can take various forms, such as an individual, a group of people, an organisation, a relationship, or a process (Yin 2018). Since the purpose of the case studies was to understand how waste processors can structure DW recovery processes in a user-centric manner to meet the requirements of CPs, "waste processing company" was selected as the suitable unit of analysis for this study.

3.4.2.1.2 Selecting between single vs. multiple case studies

Single case studies are useful when the selected case has any of the five criteria of being critical, unique, representative, revelatory or longitudinal (Saunders, Lewis & Thornhill 2019). Alternatively, multiple case studies are used when replication is needed. According to Yin (2018), the selection of the number of cases in multiple case study designs is based on the replication logic rather than the sampling logic followed in survey-based research. The author defined two types of replications: (a) literal replication and (b) theoretical replication. Literal replication is where cases are selected to predict similar results. In contrast, theoretical replication is where cases are deliberately selected to predict different results but for reasons that can be anticipated.

Since none of the five criteria for using single case studies met the requirements of this research, a single case study was not seen as appropriate. Consequently, this research followed a multiple case study design. The purpose of conducting the case studies was to understand how waste processors can structure DW recovery processes in a user-centric manner to meet the requirements of CPs. The findings from Phase I of the study revealed that CPs exhibit a higher tendency to accept and use recycled concrete aggregates (RCAs) when compared to other RCMs, indicating that they have better-met the requirements of CPs. This observation was consistent with the findings from previous studies and industry reports from Australia (justification for the selection of waste processing companies that produce RCAs from DW for Phase II of the study is explained in more detail in Section 5.3). Therefore, it can reasonably be argued that the process of producing RCAs from DW represents a current industry best practice in DW recovery in Australia. Consequently, following the literal replication logic, it was decided to undertake multiple case studies with Australian waste processing companies that produce RCAs from DW to understand the measures they have adopted when structuring their DW recovery processes to meet the requirements of CPs.

Yin (2018) argued that using multiple case study designs is likely to be more advantageous than using single case study designs. The author asserted that although single case studies can generate valuable insights, evidence from multiple case studies holds greater strength and is generally considered more compelling and robust. This viewpoint was corroborated by Voss, Tsikriktsis and Frohlich (2002), who highlighted that conducting multiple case studies enhances the quality of research findings and reduces researcher bias. Further, Merriam and Tisdell (2016) affirmed that multiple case study designs are suitable for acquiring an in-depth understanding of the context and intricacies of individual cases while

also identifying aspects that warrant comparison or contrast across cases. Therefore, rather than undertaking a single case study, attempting at least a two-case design is generally considered worthwhile (Yin 2018). Thus, a multiple case study design was deemed suitable for the current study.

Previous studies that analysed reverse logistics (RL) processes in the construction industry have also used multiple case study designs. For example, Oliveira Neto and Correia (2019) adopted multiple case studies to assess the environmental and economic advantages of adopting RL for recycling construction and demolition waste (C&DW) through case studies with construction and waste processing companies in Brazil. Likewise, multiple case studies were used by Bao and Lu (2020) to analyse the best practices followed by the C&DW recycling industry in China for sustaining long-term prosperity. Further, van den Berg, Voordijk and Adriaanse (2020) adopted multiple case studies to explore how demolition contractors process information to coordinate project activities at the end-of-life of a building. Studies such as these provided empirical support for selecting a multiple case study design for the current research.

Based on the unit of analysis and the number of cases, this research can be considered as following a multiple-case holistic design as per Yin's (2018) basic case study design types (refer to Figure 3.2).

3.4.2.2 Case study selection

According to Yin (2018), there is no specific formula for determining the number of cases to be used for a multiple case study design. Extant literature has highlighted that the number of cases selected for multiple case study designs depends primarily on the level of replication (literal or theoretical) expected through the study and the level of data saturation achieved (where new data collection sheds no further insights into the problem investigated) (Alankarage et al. 2023; Mason 2010; Yin 2018). Considering this, three cases were purposively selected for this research, expecting literal replication, while the high data saturation achieved during data analysis established the adequacy of the number of cases.

When selecting the cases, consideration was given to selecting well-established waste processing companies that had been in continuous operations for over ten years due to the anticipation of uncovering best practices in DW recovery. It was reasonably expected that such well-established cases would have more advanced and developed processes from which to draw insights for the research, a fact that was complemented by Jayasinghe

(2019). Moreover, the waste processing companies were required to have obtained the necessary licenses to operate material recovery facilities (MRFs) to be selected for the research. It should also be acknowledged that time limitations, the willingness of organisations to share information and the availability of access, especially with the ongoing COVID-19 pandemic, also affected the selection of the cases.

To identify potential case study companies for the research, a web search was conducted initially to locate waste processing companies producing RCAs from DW. Subsequently, the websites of these companies were examined, and the researcher's personal contacts were used to gain an initial understanding of the companies and the nature and scale of their operations. This preliminary assessment aimed to determine the suitability of these companies as potential case studies for the research. Additionally, information pertaining to the licensing status of the MRFs of these companies was verified using publicly available data from licensing bodies in different states. For example, information regarding MRFs licensed by the South Australian Environment Protection Authority (EPA) was accessed through the EPA website. This process led to the development of a list of potential case study companies.

Following this stage, initial contact was made with key personnel from the identified companies through email or LinkedIn, specifically focusing on engaging managerial-level employees. Details regarding such employees were obtained through company websites and LinkedIn searches. These key personnel were focused due to their influential positions within their respective companies, enabling them to make/influence decisions in support of the research. The initial email or LinkedIn message introduced the research and outlined the nature of the data expected to be collected, the proposed data collection techniques, and details regarding how the collected data would be managed in accordance with the ethics approval obtained. Upon receiving positive responses from specific companies, further information regarding the research was shared with them. Employing this approach, the researcher successfully gained access to three waste processing companies that produce RCAs from DW (referred to as Company A, Company B and Company C), which was sufficient to achieve data saturation. A snapshot of the three case study companies is provided in Table 3.2. Further details regarding the background of the companies are provided in Chapter 5 (refer to Section 5.4).

Table 3.2: Snapshot of the companies selected for the case studies

	Company A	**Company B**	**Company C**
Years in operation	30+ years	30+ years	15+ years

	Company A	Company B	Company C
Location of MRFs	South Australia (Wingfield and Lonsdale)	Victoria (Clarinda, Epping, and Laverton)	South Australia (Wingfield)
Volume of DW handled per annum (tonnes)	900,000	1,500,000	800,000
Number of employees	75-100	100-125	70-80

3.5 Research techniques

Research techniques represent the tools used for data collection and analysis. The data collection and analysis techniques employed during the two phases (Phase I – Qualitative survey and Phase II – Case studies) of the study are explained separately in detail in this section.

3.5.1 Phase I – Qualitative survey

The data collection and analysis techniques used during the qualitative survey are explained in the following sections. An overview of these techniques is presented in Figure 3.3.

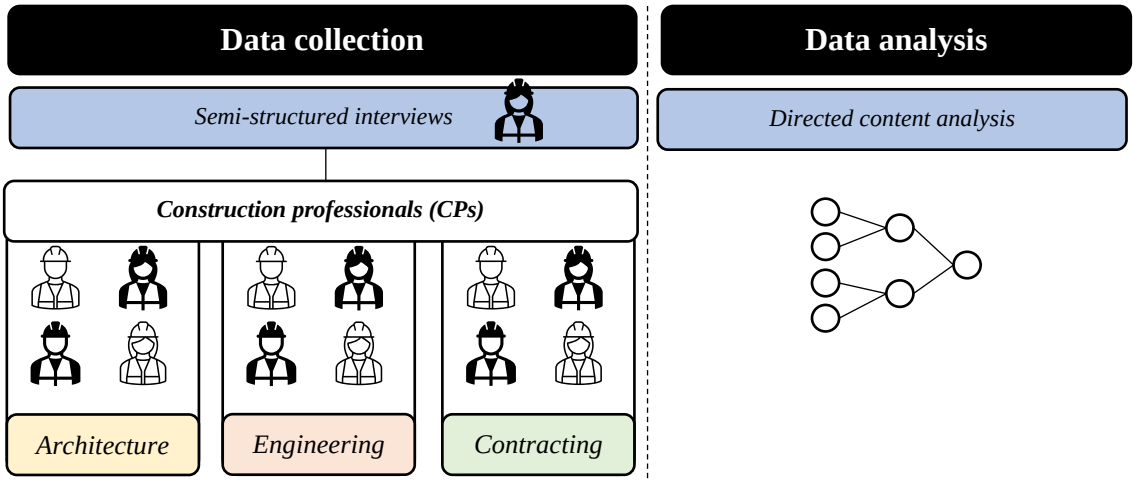


Figure 3.3: Overview of data collection and analysis techniques – Qualitative survey

3.5.1.1 Data collection

Different data collection techniques can be used under the qualitative survey approach, including interviews, observations, and documentation (Fink 2003; Jansen 2010; Merriam & Tisdell 2016). However, observations were not feasible in the context of the current research, and documented evidence regarding the uptake of RCMs in the Australian context was found to be limited. Therefore, interviews were selected as the most suitable data collection technique for this phase of the research. Interviews were defined by Saunders, Lewis and Thornhill (2019, p. 434) as "*a purposeful conversation between two*

or more people." Interviews are widely used in qualitative research to understand how people subjectively interpret social phenomena (Dunwoodie, Macaulay & Newman 2023; Jamshed 2014). Interviews help researchers uncover how people attribute meaning to their social experiences and, thereby, provide a holistic description of underexplored phenomena (Denzin & Lincoln 2005; Dunwoodie, Macaulay & Newman 2023). Likewise, interviews are known to facilitate in-depth and in-breadth exploration of issues that have not been investigated comprehensively in a particular context (Saunders, Lewis & Thornhill 2019). Considering these positive aspects, interviews were recognised as suitable for addressing the expected objectives.

According to Saunders, Lewis and Thornhill (2019), interviews can be classified into three types: structured, semi-structured and unstructured. Among these types, structured interviews are predominantly used for administering standardised questionnaires and are primarily associated with quantitative research. Alternatively, both semi-structured and unstructured interviews are used in qualitative research. Unstructured interviews are preferred in purely exploratory research, where no predefined themes or key questions guide the data collection process. In contrast, semi-structured interviews are used when a set of pre-determined themes or key questions are available to steer the data collection process. Given that Phase I of this research employed a qualitative survey approach and was informed by theoretical perspectives and previous literature on pro-environmental behaviour, the most appropriate interview type was determined to be semi-structured interviews. While semi-structured interviews involve asking the same set of questions from each interviewee, the researcher retains the flexibility to ask follow-up questions and delve deeper into emerging issues during the conversation (McIntosh, MJ & Morse 2015; Saunders, Lewis & Thornhill 2019). Moreover, this technique allows the researcher to adapt the questions based on the situation and clarify any doubts in the interviewees' responses, thereby enabling a clear understanding of the insights provided (McIntosh, MJ & Morse 2015). Such benefits further supported the selection of semi-structured interviews for this phase of the research.

Accordingly, thirty-one semi-structured interviews were conducted with CPs from architectural, engineering, and contracting backgrounds with prior experience in using RCMs. Professionals from these backgrounds were selected because they are the key actors responsible for selecting materials for construction projects and thus act as end users of RCMs in RLSCs for DW (explained in detail under Section 2.8.2.2). Moreover, according to previous literature, strategies for promoting pro-environmental behaviours,

such as the uptake of RCMs, should ideally be explored directly with representatives of the population whose behaviour is to be changed, which, in this case, are the CPs responsible for selecting materials (Stern 2000). Knowledge and experience in using RCMs was considered a key criterion in selecting the interviewees, which was crucial for developing an in-depth understanding of the uptake of RCMs. Table 4.1 in Chapter 4 presents a detailed account of the interviewees who participated in the study and highlights their experience in relation to using RCMs. Most interviewees had over ten years of experience in the industry, and insights from these well-experienced professionals enhanced the validity of the study findings.

The purposive sampling technique was adopted to identify potential interviewees best placed to comment on the uptake of RCMs. Purposive sampling is used when a study requires the selection of information-rich cases with in-depth knowledge or experience of the phenomenon of interest, especially when the availability of expertise is limited (McIntosh, MJ & Morse 2015; Palinkas et al. 2015). As highlighted previously, the current research required an in-depth exploration of the knowledge and experiences of CPs regarding the uptake of RCMs to address the first research question. However, since the use of RCMs is not well-established within the Australian context, there is a limitation of industry professionals well-versed in the use of RCMs. Therefore, purposive sampling was selected as the suitable sampling technique for connecting with CPs who have knowledge and experience in using RCMs and are best placed to comment on the uptake of such materials. Among the different purposive sampling techniques, the snowballing strategy was used for this study. This technique involved conducting initial seed interviews with select interviewees and then seeking their recommendations for other potential interviewees with expertise in relevant areas (Kyngäs 2020a). This facilitated growing the pool of interviewees and establishing connections with difficult-to-reach cases. To initiate the snowballing process, the researcher contacted several CPs via various channels, including email, LinkedIn, and telephone, upon verifying their knowledge and experience regarding using RCMs through their company and LinkedIn profiles and the researcher's contacts.

Unlike in quantitative studies, the sample size in qualitative studies is not determined before commencing the data collection process and is usually determined by the concept of saturation (Kyngäs 2020a; Mason 2010). The saturation point is defined as the point beyond which additional data collection provides no further insights into the problem being investigated (Kyngäs 2020a; Mason 2010). In this research, saturation was achieved by

22–23 interviews. However, data collection was continued up to thirty-one interviews to ensure saturation was achieved and to allow a relatively equal representation of the different professional groups considered. Altogether, the interviewees included twelve (12) professionals with a background in architecture, eight (8) with a background in engineering and eleven (11) with a background in construction contracting (i.e., experience in contractor/builder organisations). The number of interviews conducted fell within the acceptable range that methodology literature has identified as sufficient for achieving saturation in a qualitative study (Mason 2010; Saunders, Lewis & Thornhill 2019). Table 3.3 provides a snapshot of the professional backgrounds and years of experience of the interviewees (refer to Table 4.1 in Chapter 4 for further details about the interviewees).

Table 3.3: Snapshot of the professional background and years of experience of the interviewees – Qualitative survey

Classification	Number of interviewees
Based on the professional background	
Architecture	12
Engineering	08
Contracting	11
Total	**31**
Based on years of experience	
5-10 years	06
11-15 years	11
16-20 years	05
21-25 years	05
>25 years	04
Total	**31**

The interview guideline developed comprised primary questions related to the demographics of the interviewees, potential factors that limit the uptake of RCMs among CPs and potential strategies for promoting the uptake of RCMs among CPs (refer to Appendix 2(A) for the interview guideline). As suggested by Yeong et al. (2018), feedback regarding the interview guideline was obtained from two academics with expertise in construction management and reverse logistics to enhance the reliability and understandability of the questions posed. Apart from the primary questions, sub-questions or probing questions were also asked from the interviewees as the interviews progressed in order to obtain deeper insights into the specific points being raised (McIntosh, MJ & Morse 2015). As recommended by Wijewickrama et al. (2022a) and Alankarage et al. (2023), the interviewees were encouraged to provide real-life examples when responding to the questions to allow for a richer understanding of the phenomena being investigated.

The COVID-19 pandemic significantly affected the progress of data collection for Phase I, which extended from September 2021 to March 2022 and reflected a time overrun of approximately three months than initially anticipated. Conducting face-to-face interviews proved to be difficult with border closures, strict social distancing requirements, and most organisations not encouraging visitors amidst the COVID-19 pandemic. Therefore, the majority of the interviews were conducted virtually over platforms such as Zoom and Microsoft Teams. Before the interviews, in line with the ethics approval obtained for the research, each participant was emailed a participant information sheet that provided further details about the research and the nature of their involvement. A consent form was also emailed, which had to be signed by the participant, indicating their expressed consent to participate in the research. The duration of the interviews ranged between 45-60 minutes, with two interviews crossing over the 60-minute mark. All interviews were recorded with the consent of the interviewees to facilitate transcription, which also allowed the researcher to engage better with the interviewees by asking probing questions and maintaining eye contact with them throughout the interviews.

3.5.1.2 Data analysis

Following each interview, the content was immediately transcribed verbatim from the recordings using the Microsoft Word software package. This prompt transcription process allowed the researcher to identify specific areas warranting further exploration through subsequent interviews. The transcripts were also sent to the interviewees to establish accuracy and to request any clarifications or responses to follow-up questions as necessary. In total, 492 pages of interview transcripts (A4 with 1.5 line spacing) accounting for approximately 23 hours of recordings were analysed under this phase of the study. The NVivo 20 software developed by QSR International was used to organise the data for the analysis.

The nature of the data collected through semi-structured interviews is qualitative. The fullness and richness of qualitative data provide the opportunity for an in-depth analysis. Analysing large volumes of non-standardised data requires the data to be fragmented through coding and reorganising data into analytical categories (Saunders, Lewis & Thornhill 2019). As further expressed by the authors, this involves simplification and reduction of qualitative data through summarising to improve comprehension, thereby facilitating further analysis. Accordingly, the content analysis technique is widely used for analysing qualitative data to provide meaningful descriptions of human experiences and perspectives (Assarroudi et al. 2018; Hsieh & Shannon 2005; Kyngäs 2020b).

Hsieh and Shannon (2005) defined qualitative content analysis as a research technique for the *"subjective interpretation of the content of text data through the systematic classification process of coding and identifying themes or patterns*" (p. 1278). It is a technique used for describing and interpreting textual data using a systematic coding process (Assarroudi et al. 2018). A wide range of textual data from sources such as interviews, focus groups, observations, documents (e.g., articles, books, diary entries) and responses from open-ended survey questions can serve as the inputs for qualitative content analysis (Hsieh & Shannon 2005; Kyngäs 2020b). The end objective of the analysis is to identify categories, themes, and patterns in the data collected that describe the phenomena under study (Assarroudi et al. 2018; Hsieh & Shannon 2005; Kyngäs 2020b). According to previous literature, qualitative content analysis can be classified into three types as conventional, directed and summative (Assarroudi et al. 2018; Hsieh & Shannon 2005). The key difference among these three types lie in how the initial codes are developed for the analysis (Hsieh & Shannon 2005). According to Saldaña (2009), a code in qualitative research is generally a "*word or short phrase that symbolically assigns a summative, salient, essence-capturing, and/or evocative attribute for a portion of language-based or visual data*" (Saldaña 2009, p. 3). Under conventional content analysis, such coding categories are determined directly through the textual data (Hsieh & Shannon 2005; Kyngäs 2020b). Alternatively, under the directed content analysis approach, a specific theory or previous research findings are used as a guide for developing the initial coding categories (Hsieh & Shannon 2005). As the analysis progresses, the researcher has the option to develop additional codes and revise and refine the initial coding categories as required. In summative content analysis, counting or comparing keywords or content is first carried out, followed by an interpretation of the underlying context (Hsieh & Shannon 2005).

The directed qualitative content analysis technique was used during this phase of the research to analyse the data collected through the semi-structured interviews. The interviews first focused on identifying potential factors that limit the uptake of RCMs among CPs. Herein, the ABC Theory and associated literature (explained in Section 2.8.2.3) was used to guide the identification and analysis of the factors limiting the uptake of RCMs from the data collected. Next, the interviews focused on exploring potential strategies for promoting the uptake of RCMs among CPs. In this regard, the identification and analysis of such strategies were informed by previous research on informational and structural strategies for promoting pro-environmental behaviours (explained in Section

2.8.2.4). Considering that the analysis was informed by relevant theory and previous research, the directed content analysis technique was deemed suitable for this phase of the research.

The process suggested by Hsieh and Shannon (2005) for undertaking directed content analysis was adopted for this study. Initially, a preliminary set of codes was developed based on supporting theory and related literature representing the factors that could limit the uptake of RCMs among CPs and the potential strategies for promoting the uptake of such materials (explained in Sections 2.8.2.3 and 2.8.2.4). Following this, all the transcripts were reviewed carefully, and the limiting factors and potential strategies identified in the transcripts were coded against the preliminary codes where possible, while new codes were developed to capture data that could not be matched against the preliminary codes. Thus, preliminary codes were revised, refined, and added onto as the analysis progressed. Next, the generated codes were further organised into groups by identifying relationships between them and arranged under a hierarchical set of categories and subcategories, which were partly informed by extant theory and literature. Herein, the categories and subcategories developed when analysing the factors limiting the uptake of RCMs were informed by the factor classification from ABC Theory (refer to Figure 2.4 in Section 2.8.2.3). Alternatively, the classification of categories and subcategories pertaining to the strategies for promoting the uptake of RCMs was informed by previous literature from the domain of pro-environmental behaviour on classifying such strategies (refer to Figure 2.5 in Section 2.8.2.4). The process of coding the data followed an iterative approach, requiring multiple rounds of re-reading and reorganising the data until no new concepts emerged before the finalised codes and categories were established. Figure 3.4 depicts an extract from the coding process followed in identifying the factors limiting the uptake of RCMs, which highlights how the coding process was undertaken under this phase of the study.

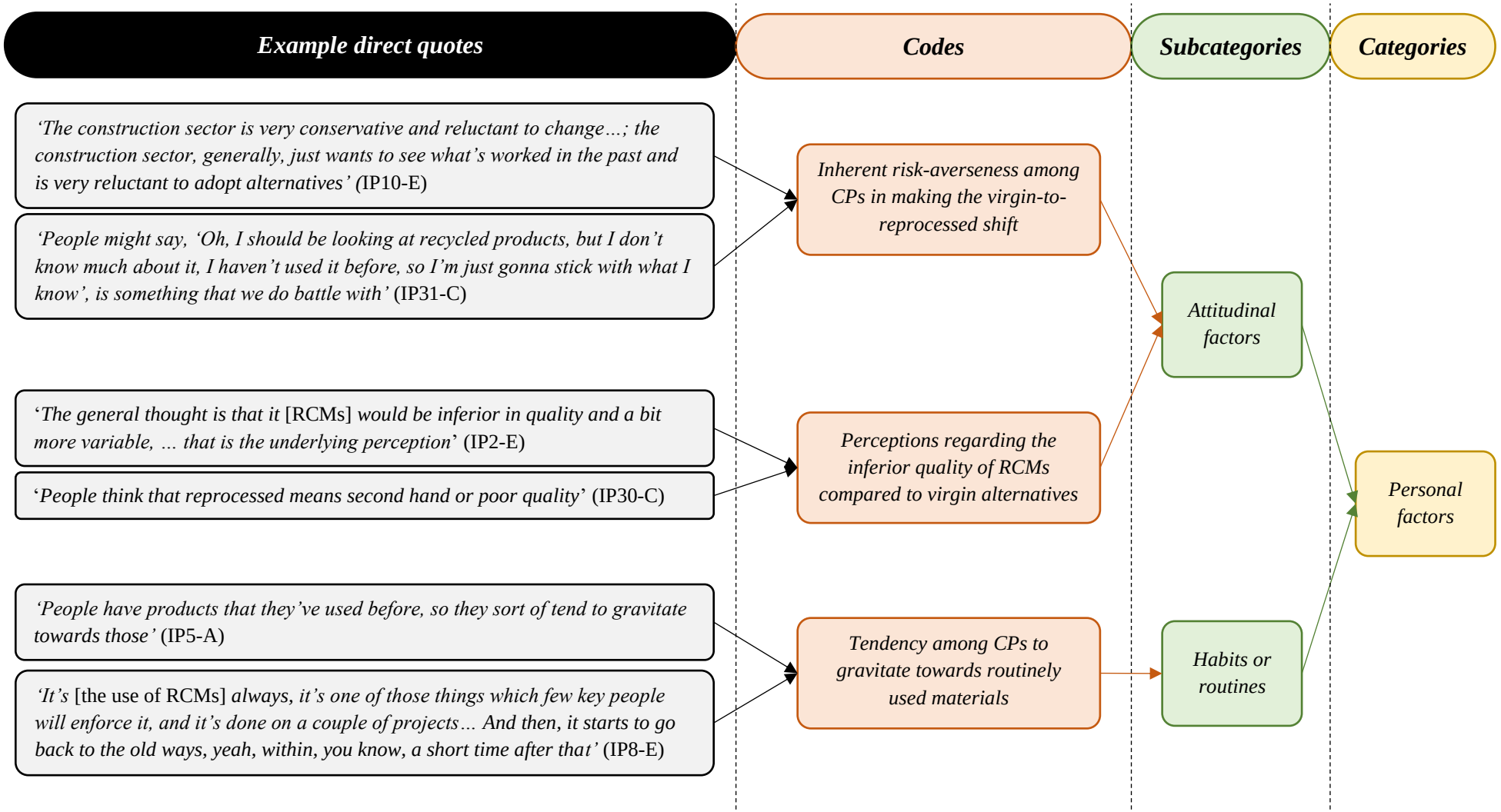


Figure 3.4: Extract from the coding process for identifying potential factors that limit the uptake of reprocessed construction materials

3.5.2 Phase II – Case studies

The data collection and analysis techniques used during the case studies are explained in the following sections. An overview of these techniques is presented in Figure 3.5.

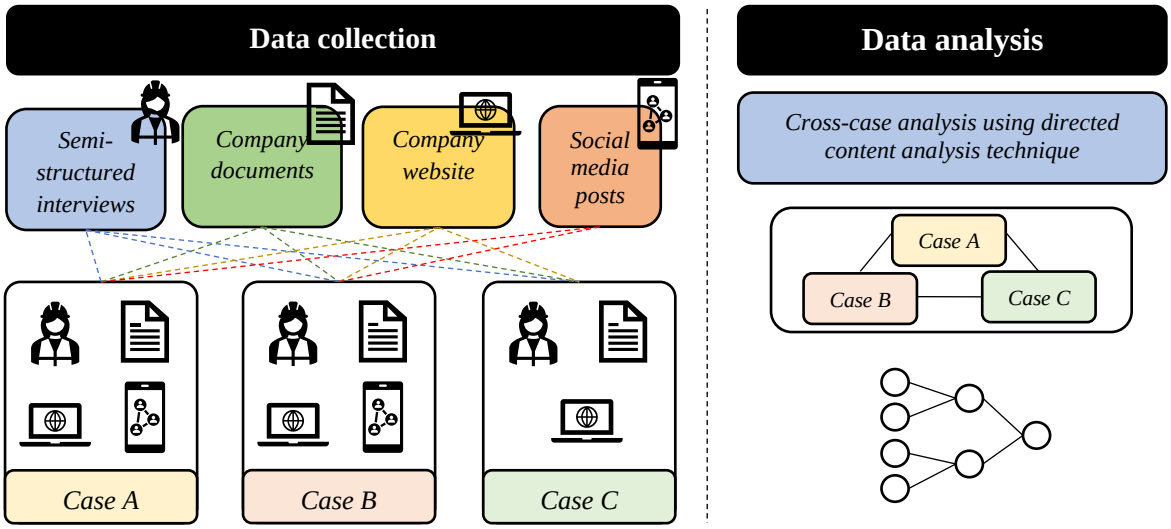


Figure 3.5: Overview of data collection and analysis techniques – Case studies

3.5.2.1 Data collection

According to Yin (2018), data for case studies can come from many sources. These can include interviews, documents, archival records, observations, and physical artefacts. Among these, interviews, documents, archival records, and observations are commonly used as data collection techniques in case study research (Alankarage et al. 2023; Eisenhardt 1989). In the current study context, conducting observations was limited by practical considerations. The data collection for this research was undertaken amidst the COVID-19 pandemic from May to November 2022. Therefore, most waste processing companies had implemented social distancing protocols and were not encouraging outside visitors, thus limiting the potential for physical observations of the MRFs. Further, with volatile border restrictions following the COVID-19 pandemic, visiting MRFs outside South Australia (the researcher was based in South Australia) was also problematic. Considering these practical difficulties, observations were not considered a viable source for collecting data in this research. Archival records, which represent data recorded over a period of time, were also disregarded, considering the limited access to such records provided by the selected waste processing companies. Consequently, document reviews and interviews were considered as data collection techniques for this study. Further details regarding the use of the two techniques are elaborated below.

Documents have been recognised by Yin (2018) as a data source that is likely to be relevant to any case study topic. “Document” is generally used as an umbrella term for a wide range of written, visual, digital, and physical materials relevant to a study (Merriam & Tisdell 2016). These can include progress reports, corporate records, newspaper accounts, photographs, videos, blogs, vlogs, etc., available in the physical environment, on websites, or both (Merriam & Tisdell 2016; Yin 2018). Documentary information was collected from the case study companies during this study. Company documents such as annual reports, company policies, product brochures, quality manuals, and web content, which were readily available, were collected as part of the data collection process. Notably, Companies A and B maintained an active presence on various social media platforms, including LinkedIn, YouTube, and Instagram. Hence, posts and videos uploaded by the two companies on these social media platforms were also included as valuable data sources for this research. Data collected from these platforms was limited to posts published from the start of the year 2022 to the point of data collection, considering the large volume of data.

Interviews were also used as a data collection technique under the case studies to verify the data collected through the document reviews and to gather additional data on the operations of the case study companies. Further documentary resources were also collected during the interviews. Among the three types of interviews (explained in Section 3.5.1.1), semi-structured interviews were selected as the most appropriate. Based on findings from Phase I, five focus areas that should be considered by waste processors when structuring DW processes in a user-centric manner to meet the requirements of CPs were identified: (1) effective marketing of RCMs, (2) enhancing the cost competitiveness of RCMs, (3) assuring the quality of RCMs, (4) ensuring reliable supplies of RCMs, and (5) traceability of RCMs to prior uses (refer to Section 5.2 for the explanation of these five areas). Therefore, interviews with the case study companies were centred on these five focus areas, rendering semi-structured interviews, which facilitate data collection in accordance with predetermined themes/ key questions, suitable. Further, the potential afforded by semi-structured interviews to collect specific information that enables comparison while also remaining flexible to ask follow-up questions and adapt the questions to delve deeper into the phenomena under study supported the selection of semi-structured interviews (McIntosh, MJ & Morse 2015; Saunders, Lewis & Thornhill 2019). An interview guideline was developed comprising introductory questions to gather background information about the companies and the interviewees, followed by questions related to the five focus areas

mentioned above (refer to Appendix 2(B) for the interview guideline). The guideline was refined based on the input of two academics with expertise in construction management and reverse logistics ahead of being used for data collection. Sub-questions or probing questions were also asked during the interviews to delve deeper into specific points raised, while the participants were encouraged to provide examples when responding to enhance the richness of the data collected (Alankarage et al. 2023; McIntosh, MJ & Morse 2015; Wijewickrama et al. 2022a).

Interviews were conducted with six interviewees from each case study company, lasting 45-60 minutes. The interviewees were nominated by the case study companies based on the information provided by the researcher regarding the specific areas of focus for data collection. These interviewees were mainly individuals holding managerial and supervisory positions, and their insights offered a comprehensive overview of the company processes. Further information about the interviewees is provided in Chapter 5, under the introduction to the case study companies (refer to Section 5.4). The interviews were conducted using a combination of face-to-face and virtual (Zoom and Microsoft Teams) formats. The choice of the interview format was based on the preferences of the individual interviewees and in line with the COVID-19 restrictions. All interviewees were requested to provide written consent for participating by signing a consent form emailed to them ahead of the interviews in line with the ethics approval obtained. Moreover, the interviewees were provided with a participant information sheet outlining details about the research and the nature of their involvement. To ensure accurate transcription of the interviews and to facilitate better interviewer-interviewee interaction, the interviews were recorded with the consent of the interviewees.

A summary of the data collection techniques used for the three cases is presented in Table 3.4. Using multiple data sources enhanced the richness of data and facilitated data triangulation, a pivotal aspect in case study research (Alankarage et al. 2023; Edwards & Holt 2010). By triangulating data from different sources, the researcher was able to enhance the quality of the study, as it allowed for the convergence of data collected from multiple sources (Carter, N et al. 2014).

Table 3.4: Summary of the data collection techniques used for the case studies

Company A	Company B	Company C
Company documents	Company documents	Company documents
Company website	Company website	Company website

Company A	Company B	Company C
Social media posts (LinkedIn and YouTube)	Social media posts (LinkedIn, YouTube, and Instagram)	Not available
Interviews (6nrs)	Interviews (6nrs)	Interviews (6nrs)

3.5.2.2 Data analysis

The data analysis involved analysing the data collected through company documents, web pages, social media posts and semi-structured interviews. After each interview with the interviewees from the case study companies, verbatim transcripts were developed using the Microsoft Word software package. This prompt transcription process allowed the researcher to determine specific areas that should be explored further through the subsequent interviews with company representatives, thus enhancing the comprehensiveness of the data collected. The transcripts were also shared with the interviewees to verify their accuracy and to request clarifications and responses to any follow-up questions. In total, 311 pages of interview transcripts (A4 with 1.5 line spacing) accounting for approximately 13 hours of recordings were analysed during this study phase. NVivo 20 software, developed by QSR International, was used to organise the documentary and interview data for the analysis.

A cross-case analysis was carried out to analyse the data from the case studies, following the directed content analysis technique. As with the first phase, the directed content analysis technique (explained in Section 3.5.1.2) was deemed suitable for analysing the data since the analysis was informed by the findings from Phase I of the study and previous literature on RL, while the technique allowed new codes to be developed from the data as well. The analysis was directed along the five focus areas revealed under Phase I of the study as the areas that waste processes should focus on when structuring DW recovery processes in a user-centric manner to meet the requirements of CPs. These areas include: (1) effective marketing of RCMs, (2) enhancing the cost competitiveness of RCMs, (3) assuring the quality of RCMs, (4) ensuring reliable supplies of RCMs, and (5) traceability of RCMs to prior uses (refer to Section 5.2 for the explanation of these five areas).

In line with the process suggested by Hsieh and Shannon (2005) for undertaking directed content analysis, a set of preliminary codes was developed based on Phase I findings and the review of literature on RL. Next, the interview transcripts and other documentary resources were scrutinised carefully, and the measures taken by the case study companies to achieve the five focus areas mentioned above were coded against the preliminary codes where possible while new codes were developed to capture data that could not be matched

with the preliminary codes. The preliminary codes were revised, refined, and added onto as the analysis progressed. Following this initial coding process, the generated codes were further organised into groups by identifying relationships between them to form a hierarchical set of categories and sub-categories. Coding the data was an iterative process that involved re-reading and reorganising the data multiple times until no new concepts emerged before arriving at the finalised codes and categories. Figure 3.6 depicts an extract from the coding process followed. Different forms of presenting case study data, including narrative descriptions, tabular displays, and graphical representations, as suggested by Eisenhardt (1989) and Voss, Tsikriktsis and Frohlich (2002), were used to present the findings from the cross-case analysis effectively.

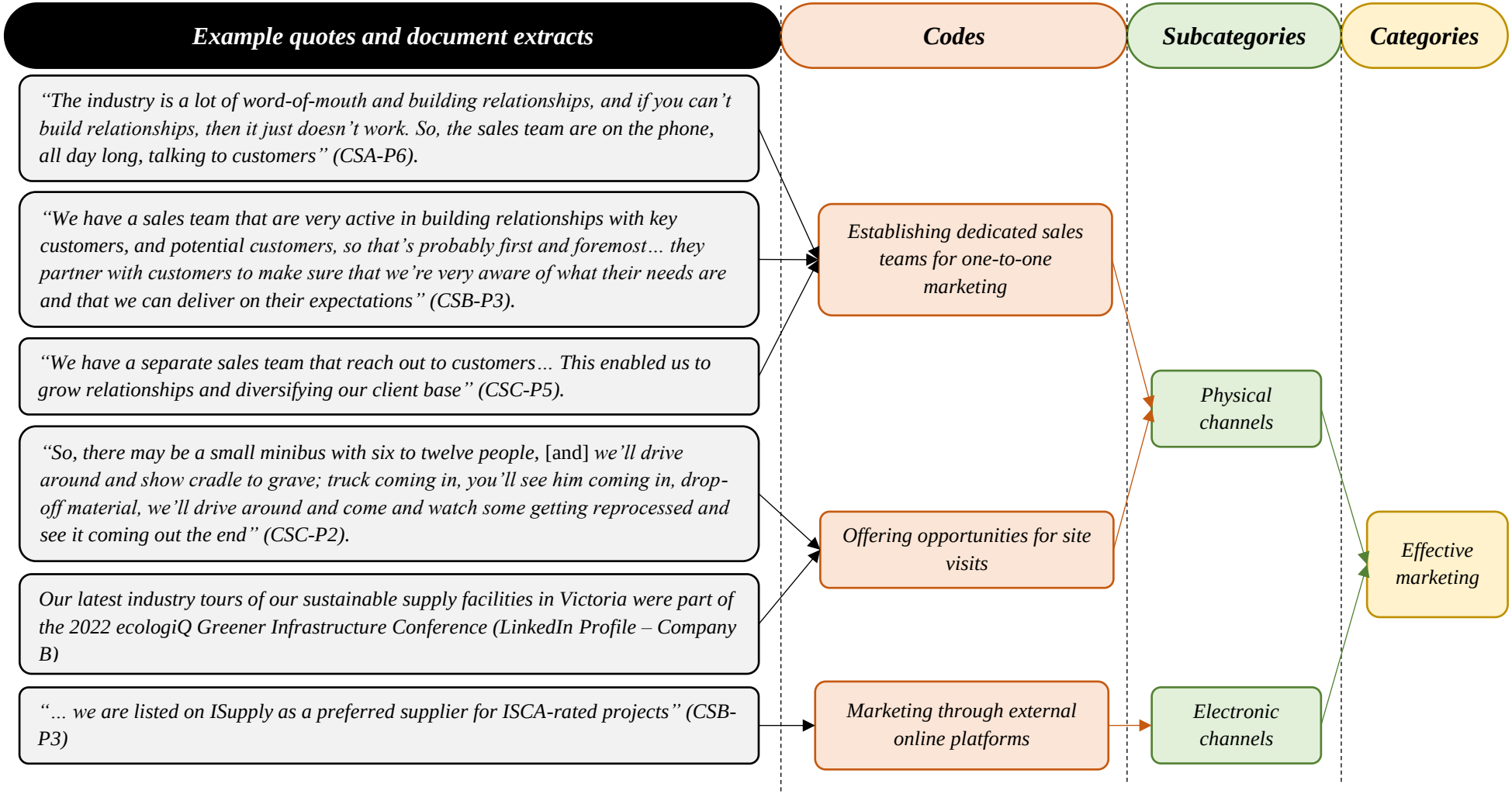


Figure 3.6: Extract from the coding process followed in analysing the data from the case study companies

The findings from the cross-case analysis led to the development of a best-practice framework for a user-centric DW recovery process (refer to Section 5.6), which identifies the measures that can be taken by waste processors for structuring DW recovery processes in a user-centric manner to meet the requirements of CPs. This developed framework was then validated using expert interviews to evaluate its practical applicability, as advocated by Preece (2001). Semi-structured interviews were used for the validation exercise owing to their characteristics as explained in Section 3.5.1.1 (i.e., in-depth and flexible nature of inquiry), and these interviews were conducted with four interviewees purposefully selected from academia and industry (refer to Appendix 2(C) for the interview guideline). The interviews were recorded, transcribed and analysed following the directed content analysis technique. The framework was evaluated based on criteria including ease of understanding, completeness, and usefulness, which have been used in prior studies to evaluate the practical applicability of frameworks developed based on the outcomes of qualitative studies (Gunatilake 2013; Kulatunga 2008). A detailed explanation regarding the validation exercise in presented in Section 5.7.

3.6 Trustworthiness of the research findings

In qualitative research, trustworthiness refers to the degree of confidence (rigour) associated with the data, the interpretations, and the methods adopted to ensure the quality of the research findings (Polit & Beck 2010). Given the distinct assumptions about reality in qualitative research compared to quantitative research, the criteria for assessing the quality or rigour of qualitative research differ from those used in quantitative research (Merriam & Tisdell 2016). Guba (1981) proposed four aspects for determining the quality of empirical qualitative social research: truth value, applicability, consistency, and neutrality. The following sections highlight how these aspects were achieved in the current research to ensure the trustworthiness of the research findings.

The **truth value** considers how one can "*establish confidence in the truth of the findings of a particular inquiry*" (Guba 1981, p. 79), thus establishing its credibility. One approach to establishing truth value involved engaging well-experienced participants throughout both phases of the research, who expressed interest and willingness to participate. Additionally, member checks were employed as another strategy to enhance truth value (Guba 1981; Merriam & Tisdell 2016). As part of this process, the interview transcripts from both research phases were shared with the interviewees for verification before data analysis, thus limiting the potential for misinterpreting the findings. However, not all of them

responded. Furthermore, the triangulation of data sources during Phase II and the comparison of findings from both phases of the study against the broader body of literature under the discussion chapter (refer to Chapter 6) further contributed towards establishing the truth value of the research. Lastly, data collection was continued until saturation was achieved, which was another strategy used for establishing the truth value of the research as advocated by Merriam and Tisdell (2016).

Applicability, which concerns the extent to which the findings of a particular study can be applied to other contexts, aligns with the concept of generalisability commonly employed in quantitative research (Guba 1981; Merriam & Tisdell 2016). However, generalisability in a statistical sense cannot be achieved in qualitative research (Merriam & Tisdell 2016). Therefore, this research employed techniques proposed for establishing applicability in qualitative studies. Herein, quotes from interview transcripts were incorporated when presenting findings from both phases of the study (refer to Chapters 4 and 5), thus allowing readers to relate the experiences of the interviewees to their own personal experiences. Additionally, the research provided comprehensive and detailed descriptions of the research setting and findings, facilitating the transferability of the research outcomes to other contexts. Furthermore, using multiple cases following the literal replication logic during Phase II further enhanced the applicability of the research.

Consistency refers to the potential for generating similar findings if the research is repeated using similar procedures (Guba 1981; Merriam & Tisdell 2016). Consistency was ensured in this research by providing a clear audit trail of the path followed by the researcher in arriving at the research findings. Detailed descriptions of how data was collected and analysed and how decisions were made throughout the research process were provided in the methodology chapter. Furthermore, using interview guidelines for conducting interviews during both phases of the research also contributed towards establishing consistency. **Neutrality** refers to the extent to which the research findings are free from the researcher's biases, motivations, interests, and perspectives (Guba 1981). As mentioned earlier, providing a clear audit trail documenting the research process promoted transparency and allowed for assessing potential subjective influences. Triangulation of data sources under Phase II and the comparison of research findings against extant literature under the discussion chapter further contributed towards establishing neutrality.

3.7 Ethical considerations

A major significance should be placed upon the ethical conduct of research, especially where research involves the participation of human subjects (Saunders, Lewis & Thornhill 2019). According to Yip, Han and Sng (2016), conducting ethical research involves ensuring the safety, integrity, dignity, right to self-determination, and confidentiality of the research participants. This research was primarily based on the knowledge and expertise of professionals from the construction and waste processing industries. Therefore, it was imperative to obtain ethics approval as per the National Statement on Ethical Conduct in Human Research (National Health and Medical Research Council: Australian Government 2018), which requires all research conducted with human participants to obtain ethics approval. Consequently, ethics approval was granted for the current research by the University of South Australia's Human Research Ethics Committee on the 6th of July 2021.

In line with the ethics approval obtained, participants were provided with a participant information sheet at all stages of data collection, which contained details regarding the purpose of the research, the nature of their involvement and other pertinent information related to the rights of the participants, data management, and avenues for obtaining further information about the research. To obtain written consent for participation, all participants were requested to sign a consent form indicating their understanding of the nature of their involvement in the research project and their willingness to participate. All data collected were stored securely in password-protected computers and access-controlled locations. The confidentiality and anonymity of the participants were maintained throughout the data analysis and reporting stages. Special attention was given to ensuring the authenticity of the collected data during the reporting process.

3.8 Chapter summary

This chapter presented the research methodology adopted for this research, which included the philosophical position of the research, the research approaches followed and the research techniques used for data collection and analysis. This research was conducted in two phases. Phase I involved a qualitative survey, which focused on identifying potential factors that limit the uptake of RCMs among CPs and exploring potential strategies for promoting the uptake of such materials. Herein, interviews were undertaken with thirty-one CPs from architectural, engineering, and contracting backgrounds with prior experience in using RCMs. The data collected from these semi-structured interviews were analysed using the directed content analysis technique. Phase II of the research involved

case studies with three waste processing companies that produce RCAs from DW. The purpose of the case studies was to gain insights into how waste processors can structure DW recovery processes in a user-centric manner to meet the requirements of CPs. Document reviews and semi-structured interviews were used as data collection techniques under the case studies, and a cross-case analysis using the directed content analysis technique was carried out for data analysis. The findings from the cross-case analysis led to the development of a best-practice framework for a user-centric DW recovery process, and aspects related to validating this framework were also explained in this chapter. Furthermore, the chapter also discussed the steps taken to ensure the trustworthiness of the research findings and ethical considerations. The next chapter presents the findings from the qualitative survey.

CHAPTER FOUR: FINDINGS – QUALITATIVE SURVEY

4.1 Introduction

The purpose of this chapter is to explore how the uptake of reprocessed construction materials (RCMs) can be promoted among construction professionals (CPs). According to the literature on pro-environmental behaviour, such behaviours can be promoted through a five-step process that includes (1) identifying the pro-environmental behaviour to be changed, (2) identifying the responsible actors and actions, (3) identifying the factors that limit the behaviour, (4) exploring potential strategies for promoting the behaviour, and (5) applying and evaluating the effectiveness of the strategies (Refer to Section 2.8). The pro-environmental behaviour to be changed in the context of this study is the uptake of RCMs, and CPs were identified as the key actors responsible since they are primarily responsible for selecting materials for construction projects (Refer to Sections 2.8.2.1 and 2.8.2.2). This chapter focuses on steps three and four, involving the identification of factors that limit the uptake of RCMs among CPs and strategies for promoting the uptake of such materials, which also formed the first two objectives of this study. This chapter explains findings related to these two areas in detail. Step five, which focuses on applying and evaluating the effectiveness of the strategies identified, was outside the scope of this study due to reasons explained in Section 2.8.2.5. The limiting factors and strategies were identified through a qualitative survey approach, which involved undertaking semi-structured interviews with CPs involved in material selection. Demographic information of the interviewees is presented in the next section, followed by the findings related to the factors that limit the uptake of RCMs among CPs and strategies for promoting the uptake of such materials.

4.2 Demographic information of interviewees

Under Phase I, thirty-one (31) semi-structured interviews were conducted with CPs involved in material selection decisions and having prior experience with projects using RCMs. The interviewees included twelve (12) professionals with a background in architecture, eight (8) with a background in engineering and eleven (11) with a background

in construction contracting (i.e., builders). Table 4.1 presents a detailed account of the interviewees who participated in the study. The column “Professional Highlights” emphasises the experience of the individual interviewees with the use of RCMs, which was considered a key criterion for selecting these professionals for the study. The analysis was also supported by some documentary resources provided by the interviewees during the interviews.

Table 4.1: Profile of the interviewees [Interviewee Code: IP1-E – Represents interviewee number and professional background]

Code	Designation	Background	Experience	Professional Highlights
IP1-E	Supervising Engineer	Engineering	30 years	IP1-E is involved in material research, testing, and developing specifications for infrastructure projects in South Australia. IP1-E played a primary role in developing South Australian infrastructure specifications for RCMs and is an active member of Austroads – the apex body for road transport and traffic agencies in Australia and New Zealand that publishes best-practice guidelines, codes of practice and research reports for road management.
IP2-E	Civil Team Leader	Engineering	06 years	IP2-E is the Civil Team Leader for a leading engineering consultancy organisation. IP2-E is experienced in using RCMs for roads, walking trails, and other public spaces. IP2-E also supports local government initiatives by developing various guidelines, streetscape reconstruction projects and innovative construction practices.
IP3-A	Principal of Research and Development	Architecture	13 years	IP3-A holds a PhD in Architecture and heads the research and development arm of a leading architectural practice in Australia. The primary role of IP3-A is to develop a nexus between industry practice and academic research, thereby sparking design innovation and advancements in the built environment.
IP4-A	Architect and Project Lead	Architecture	08 years	IP4-A is a licensed architect with prior experience in using RCMs for residential and small-scale commercial projects.
IP5-A	Associate Director and Head of a company-based sustainability forum	Architecture	20 years	IP5-A is an experienced architect with a deep understanding of sustainability and regenerative design concepts and is a member of several professional organisations and committees in the sustainability field. IP5-A also heads a company-based sustainability forum that shares sustainability-related knowledge across different design studios in Australia and students interested in sustainability.
IP6-A	Associate and Senior Heritage Architect	Architecture	21 years	IP6-A has more than 15 years of experience in the architectural heritage and conservation field – a field that regularly uses RCMs. IP6-A has also completed further studies on material conservation and is engaged as a Heritage Advisor for the South Australian and Victorian Governments.

Code	Designation	Background	Experience	Professional Highlights
IP7-E	Team Manager for Volume Housing	Engineering	12 years	IP7-E specialises in developing construction funding reports for volume builders and is focused on incorporating sustainability concepts into volume housing projects that traditionally follow low-cost conventional construction approaches.
IP8-E	Associate Senior Civil Engineer and Chair of a company-based sustainability and environmental forum	Engineering	17 years	IP8-E is experienced in using RCMs for infrastructure projects in Australia and New Zealand. IP8-E is also the Chair of the sustainability and environmental forum of a reputed Australian engineering consultancy organisation that advocates using environmental practices during construction (primarily waste management and material sourcing).
IP9-E	Senior Civil and Environmental Engineer	Engineering	14 years	IP9-E is involved in projects under Victoria's Big Build that promote the use of RCMs for road and rail infrastructure projects.
IP10-E	Senior Structural Engineer	Engineering	15 years	IP10-E is experienced in using RCMs for construction projects in Australia and Ireland and is an active member of a company-based sustainability and environmental forum that promotes the widespread use of sustainable construction practices.
IP11-C	Design Manager	Contracting	34 years	IP11-C is primarily involved in design-and-build projects and advises clients on buildability, futureproofing, and life cycling. IP11-C also advocates sustainable construction and is a Green Star-accredited professional with long-standing experience in developing Green Star-rated projects.
IP12-C	Managing Director	Contracting	12 years	IP12-C leads a construction organisation specialising in energy-efficient custom homes and building to Passivhaus (Passive house) standards with a priority focus on sustainable residential construction.
IP13-E	Principal Sustainability Advisor	Engineering	12 years	IP13-E is experienced in various sustainability-related roles that include providing input to master specifications, developing sustainability requirements for public-sector contracts, and capacity building related to sustainability. IP13-E is involved in developing infrastructure specifications for RCMs and promoting sustainable procurement for South Australian public sector projects.
IP14-C	Managing Director	Contracting	25 years	IP14-C leads a Tier-02 construction organisation and is experienced in using RCMs for multiple residential and small-scale commercial projects.

Code	Designation	Background	Experience	Professional Highlights
IP15-C	Project Manager	Contracting	13 years	IP15-C is experienced in using RCMs for multiple residential and small-scale commercial projects.
IP16-C	Project Manager	Contracting	15 years	IP16-C is experienced in using RCMs for multiple residential and small-scale commercial projects.
IP17-A	Senior Architect	Architecture	14 years	IP17-A is an experienced architect who has led several projects that used RCMs.
IP18-A	Director	Architecture	12 years	IP18-A is an award-winning architect and the head of a growing architecture firm with projects across three states in Australia. The firm specialises in sustainable design practices, such as modular, prefab, and adaptive reuse, focusing on the efficient use of materials.
IP19-A	Design Manager	Architecture	14 years	IP19-A works for a leading urban development agency and has experience working with a sustainable design and consultancy organisation focused on advising, analysing, and designing climate-responsive built environments. IP19-A has experience in designing projects with RCMs in Europe and Australia.
IP20-A	Director	Architecture	25 years	IP20-A co-leads an architectural practice that has embedded sustainable design as an intrinsic aspect of the design process, with multiple residential projects completed to meet sustainability criteria such as efficient material usage and waste minimisation.
IP21-A	Director	Architecture	17 years	IP21-A leads a residential architectural practice focusing on sustainability, low-energy, and zero-carbon design, where efficient use of materials is a primary focus area.
IP22-E	Senior Principal Civil and Traffic Engineer	Engineering	26 years	IP22-E is a senior engineer with experience in using RCMs for roads and other paving (e.g., car park) projects.
IP23-A	Associate (Consultant in Environmentally Sustainable Design (ESD))	Architecture	10 years	IP23-A is a Green Star and WELL Accredited Professional with experience in sustainable design, emission reduction, environmental management, waste minimisation, and sustainability policy areas. IP23-A specialises in strategic sustainability planning and has been involved in major projects, including the development of carbon-positive plans, regional sustainability plans, and precinct master plans.

Code	Designation	Background	Experience	Professional Highlights
IP24-A	Director (Specific focus on heritage conservation)	Architecture	32 years	IP24-A has over 25 years of experience in heritage conservation and specialises in adaptive reuse projects that regularly use RCMs.
IP25-C	Project Manager	Contracting	10 years	IP25-C has experience in using RCMs for multiple construction projects and has worked on several Green Star-certified projects.
IP26-C	Construction Manager	Contracting	18 years	IP26-C has experience in delivering multiple Green Star (five-star) certified building projects.
IP27-A	Architect and Project Lead	Architecture	20 years	IP27-A is an architect and a project lead for an architectural, design, and sustainability consultancy practice explicitly established to address the demand for sustainable architecture in Australia.
IP28-C	Project Manager	Contracting	06 years	IP28-C represents a company specialising in delivering projects complying with sustainability rating tools.
IP29-C	Project Manager	Contracting	08 years	IP29-C has experience in using RCMs for multiple residential construction projects.
IP30-C	Project Manager	Contracting	21 years	IP30-C has experience in sustainable construction and was involved in an award-winning environmental and sustainable construction project.
IP31-C	Project Manager	Contracting	25 years	IP31-C has experience in using RCMs for multiple residential construction projects.

4.3 Factors limiting the uptake of reprocessed construction materials among construction professionals

Attitude-Behaviour-Context (ABC) Theory was used in this study to support the identification and classification of factors that could limit the uptake of RCMs among CPs. Aligned with ABC Theory, the study identified multiple personal and contextual factors that could potentially limit the uptake of RCMs among CPs. These factors are presented in detail in this section.

4.3.1 Personal factors limiting the uptake of reprocessed construction materials among construction professionals

The personal factors that limit the uptake of RCMs among CPs were classified under three broader sub-categories: (1) attitudinal factors, (2) personal capabilities, and (3) habits or routines. A summary of these factors is shown in Figure 4.1, with detailed explanations presented in the following sections.

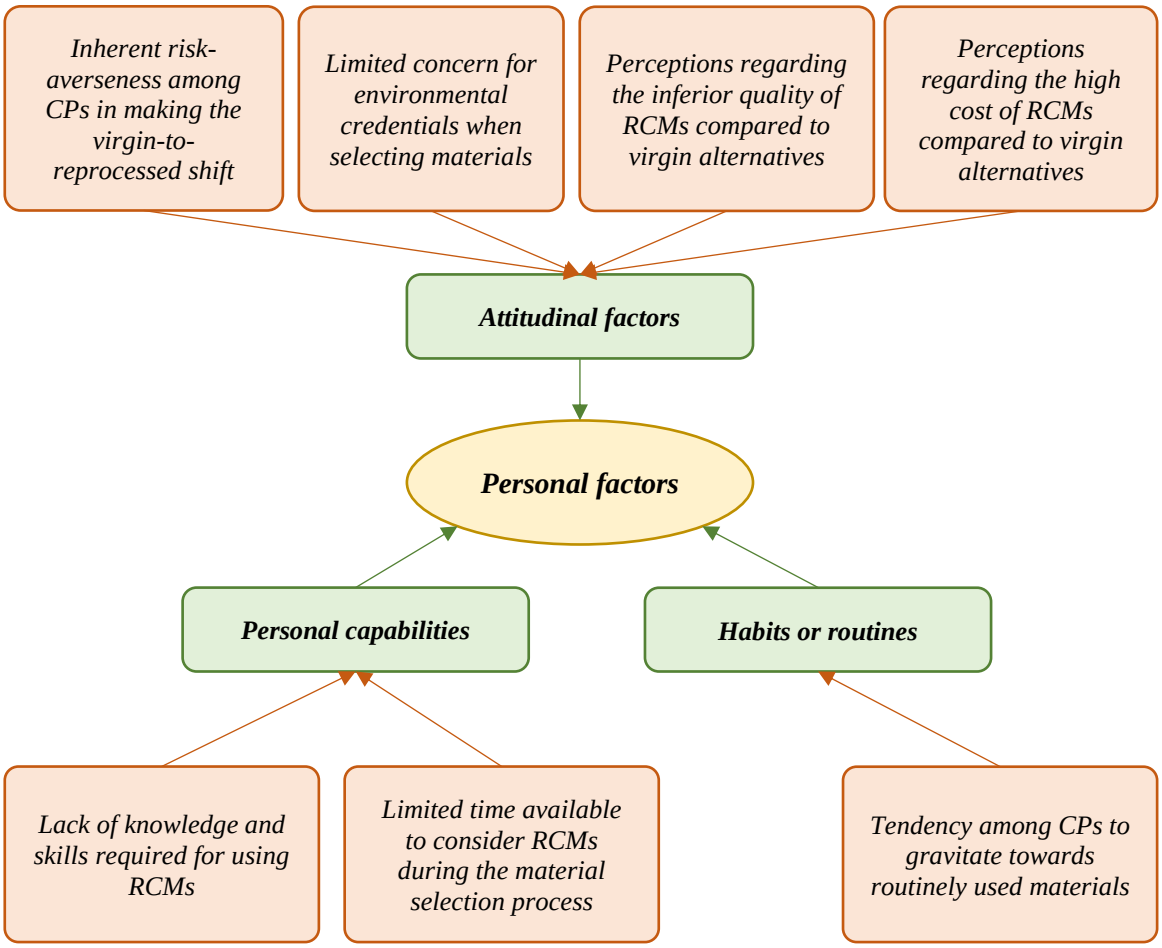


Figure 4.1: Summary of personal factors that limit the uptake of reprocessed construction materials among construction professionals

4.3.1.1 Attitudinal factors

Attitudes refer to predispositions or tendencies to respond positively or negatively towards a particular idea, object, person, or situation. While positive attitudes toward pro-environmental behaviours reinforce such behaviours, negative attitudes discourage them. Several such negative attitudinal factors that limit the uptake of RCMs among CPs were identified through the interviews. These include (1) the inherent risk-averseness among CPs in making the virgin-to-reprocessed shift, (2) the limited concern for environmental credentials when selecting materials, (3) perceptions regarding the inferior quality of RCMs compared to virgin alternatives, and (4) perceptions regarding the high cost of RCMs compared to virgin alternatives, which are explained in detail in the following sections.

4.3.1.1.1 Inherent risk-averseness among CPs in making the virgin-to-reprocessed shift

The interview findings highlighted that CPs have a natural tendency to avoid risks, which poses a challenge when attempting to introduce changes in the industry. Elaborating on this, IP10-E expressed:

> The construction sector is very conservative and reluctant to change…; the construction sector, generally, just wants to see what's worked in the past and is very reluctant to adopt alternatives.

This inherent risk-averseness among CPs has also affected the uptake of RCMs since it has led them to believe that shifting to RCMs from virgin materials, with which they do not have experience, is a risky venture. As affirmed by IP2-E, "*As this is a somewhat new technology, there's some hesitancy around it*." Most CPs prefer to use materials that have been in use for a long time and those they have experience using because it gives them a sense of security over their material choices. IP31-C highlighted this as a battle that the advocates of RCMs face:

> People might say, 'Oh, I should be looking at recycled products, but I don't know much about it, I haven't used it before, so I'm just gonna stick with what I know', is something that we do battle with.

Introducing RCMs to such risk-averse professionals is problematic since they do not wish to take the chance on a RCM and be the 'project that failed'. Reputation has a strong influence on the ability of CPs to attract future projects. Being associated with a failed project can tarnish their reputation, and therefore, they try to minimise their risk by limiting themselves to tried and tested material options. As expressed by IP18-A, "*People believe there's a level of security when you go with a tried and tested product; it removes all of that risk.*" IP3-A asserted that the risk-averseness of CPs would be more of a problem when using RCMs in large-scale public or commercial projects than in residential projects since the negative connotations associated with failures in such projects can be much higher.

It is also uncertain who should accept the risk if a failure occurs as a result of using RCMs. As emphasised by IP3-A, "*Who's responsible if it fails…I think that's a key issue.*" IP18-A mentioned that this risk could, in most cases, fall on the builders since they are responsible for providing performance certificates and other guarantees and warranties that obligate them to rectify failures. However, architects and engineers cannot avail themselves of this responsibility since they are also responsible for material selection. IP3-A elaborated on this as follows:

> If I'm thinking about how it works on site, generally speaking, just like if a plumber is doing pre-lays in the ground, they have to sign-off that what is in there, you know, meet standards and codes…But sometimes, while generally, if something happens, and there's a large failure, they might start pointing to the designer at the very beginning to say, well, why did you specify that when you can't guarantee the performance, so could you not have achieved the same result without the risks?

In such an environment, CPs are unwilling to take the initiative and use RCMs since the responsibility for any failures in these materials can ultimately come back to them. As opined by IP17-A, "*There's a bit of a leap of faith in trying something new*", and not everyone is willing to take that leap. IP3-A and IP21-A further noted that owing to their risk-averseness, CPs might charge very high premiums when requested to use RCMs, thus making it economically unattractive to use such materials.

On the other hand, if the request to use RCMs comes from another party, then more CPs will be open to using RCMs. Herein, architects and engineers will be happy to use RCMs if the requirement to do so comes from the client. Any risks will then be with the client who initiated the request. This was supported by IP4-A, who stated that "*It comes back to the client if they* [clients] *are passionate about it; then they'll* [designers] *suggest that...it's the responsibility of the client if anything goes wrong*." Similarly, builders want the consultants or clients to accept any risks of using RCMs. As expressed by IP15-C, "*Builders need the consultants to specifically specify that they want reprocessed, and by that, they are then accepting the risk, and the client is accepting the risk on it.*" IP16-C added that in such a scenario, if a specified material fails, builders could say, "*Well, you specified it; that's back on you, Mr Client or Mr Architect,*" and avail themselves of any risks.

It is noteworthy to highlight that some CPs tend to use RCMs in cases where risks are low, such as for their personal projects. For example, IP3-A mentioned:

> "I know architects, especially the ones that are doing things for themselves on a small scale, let's say, like residential, do already use recycled materials. I know of many that have, you know, done their home and home extensions, their own ones or their friends' ones on a small scale."

This further affirms the finding that the risk averseness of CPs can influence the uptake of RCMs and that there is more opportunity for using RCMs when the perceived risks are low.

4.3.1.1.2 Limited concern for environmental credentials when selecting materials

The interview findings indicated that CPs assign less importance to the environmental credentials of materials when making decisions around materiality. Where two material options are comparable in terms of other aspects, the selection decision could be based on the environmental credentials of the individual materials. However, in other cases, environmental credentials will generally rank low on the list of priorities for material selection. IP17-A explained this as follows:

> If there were two flooring options that, you know, looked good; one was from a company that was, you know, horrible to the environment and one that used recycled materials, maybe then people will say, let's go with the one that's greener. But they don't dial at the point of let's just find, you know, green or recycled, reconstituted materials and start there.

This was affirmed by IP10-E, who expressed that the construction industry is yet to mature in terms of considering the environmental impacts of different material options during the material selection process. Similarly, IP11-C added that CPs, although seemingly open to the idea of "going green," rarely follow through with this idea. Instead, most of their decisions around materiality are predominantly based on cost and ease of access. Consequently, this has led to RCMs being relegated to a secondary position behind less environmentally-friendly alternatives.

The findings resonated that economic considerations continue to be the primary driver of most decisions regarding materiality. Therefore, if environmentally-friendly materials like RCMs are more costly to use than conventional materials, they would generally be disregarded in the pursuit of lower costs. As affirmed by IP4-A, "*A lot more time, it's literally down to the dollars, to be honest*." Builders, in particular, were accused of following a cost-leadership approach to construction, which has resulted in environmental considerations going by the wayside. According to IP5-A, "*Builders don't really care per se; most of them are driven by money, that's the ultimate value.*" IP8-E highlighted that builders only care about alternatives that increase their return rather than focusing on the greater good and that builders are "*not in it to make friends or save the world*" but "*to make money*." In fact, interviewees from contracting backgrounds themselves affirmed that most builders have such mindsets. For example, IP12-C, the Managing Director of a construction company, expressed that the bulk of the builders "*just want to get whatever is the cheapest of the cheapest, win the job, get it built, and move on to the next one*.".

Concerns were expressed regarding industry perceptions of RCMs as being merely "nice to haves" that only a minority of individuals would be interested in rather than being

considered an integral aspect of any project. Such perceptions must be changed in the efforts to improve the uptake of RCMs and make it more of a norm to use these materials. As echoed by IP3-A,

> It needs to be celebrated a bit more to make it mainstream as opposed to a 'nice to have' that, you know, like the greenies might use. It's good to shift away from that thinking that it's something that a small minority use and make it more the norm.

Interestingly, some interviewees also noted a growing shift in the attitudes of CPs towards achieving better environmental outcomes through material selection. IP23-A, who also has experience in ESD consultancy, stated that interest in this area is growing and that CPs are starting to look at the environmental credentials of material options, especially with the evolving discussions around climate change and embodied carbon mitigation in the backdrop of the 2050 net zero emissions commitment of the Australian Government. IP11-C, IP15-C, and IP16-C stated that some architects have started to promote this shift by providing specialised advice on green architecture, especially for residential construction projects. Similarly, IP5-A, IP12-C, IP13-E, and IP19-A also noted that some builders are embracing this change and are promoting themselves as sustainable builders while setting up sustainability arms within their businesses. Although concerns about achieving better environmental outcomes are improving, it is slow and not yet mainstream. As explained by IP5-A, "*It's still very much not mainstream yet…we are not there yet by any means*." Consequently, IP18-A highlighted that more work should be put in to change the mindsets of CPs to encourage them to consider the environmental credentials of materials when making decisions around materiality, thereby offering a competitive edge for RCMs over virgin alternatives.

4.3.1.1.3 Perceptions regarding the inferior quality of RCMs compared to virgin alternatives

According to the interview findings, the preconceived idea among CPs that the quality of RCMs is inferior to that of virgin materials acts as a significant roadblock in promoting the uptake of RCMs. IP2-E commented, "*The general thought is that it* [RCMs] *would be inferior in quality and a bit more variable…that is the underlying perception.*" The interviewees asserted that when the discussion around using RCMs is brought up, people tend to make assumptions about the poor quality of these materials and reject them without any further consideration. As expressed by IP30-C, "*People think that reprocessed means second hand or poor quality.*" IP28-C alluded to this notion and highlighted that "*It is the human nature to want 'brand new' instead of 'second hand'; this perception of new is*

better is a major contributor". Due to such negative perceptions, CPs believe that the durability of a structure could be affected if RCMs were used. Study findings also suggest that these negative quality perceptions can have a stronger influence on the use of RCMs for structural applications where there is a greater responsibility on the part of CPs to ensure structural soundness. IP11-C corroborated this notion by highlighting his prior experiences:

> There have been a few projects where engineers have been very nervous about using certain materials, especially in a structural sense, so it's that, again, consistency and quality of the material versus a new product.

IP2-E, IP13-E, IP21-A, and IP23-A further indicated that these negative perceptions could be reinforced through previous experiences with poor-quality RCMs. In such cases, these perceptions could become difficult to change, albeit experienced in very few cases or experienced before a long time. This is made abundantly clear through the following comment by IP13-E:

> There are contractors who may have had bad experiences in the past with a product that, you know, didn't perform well, or they had to, you know, had to do rework, and then, that negative perception influences them. Even if it was years and years ago, and it was just one project, the perception will be, you know, recycled materials don't perform. So, I think we're facing that sort of opinion in some cases.

IP23-A supported the above comment with a real-life example, where the interviewee had to reconsider using RCMs due to the negative stance maintained by the project contractor against such materials based on a previous bad experience. IP23-A elaborated on this situation as follows:

> I have had one builder have issues with recycled content; I think it was recycled content in pavers and landscaping kind of materials that didn't meet their requirements. They had to rip it all out, and now, they've got a very strong stance against it. That made it, yeah, that quality issue, that really kind of made it more difficult moving forward.

These findings suggest that promoting the uptake of RCMs requires an attitudinal shift across the industry to address the negative perceptions regarding the quality of these materials.

4.3.1.1.4 Perceptions regarding the high cost of RCMs compared to virgin alternatives

There is a general perception among CPs that using RCMs is costlier than using virgin materials. As commented by IP4-A, "*Often, to be honest, it's always been the perception of yeah, that it's, the recycled, are usually more expensive.*" CPs consider cost as a key decision criterion in material selection since they have to work within client budgets, and

builders specifically see it as a determinant of their market competitiveness. Therefore, the perception of higher costs discourages CPs from considering RCMs. Similar to the perceptions about poor quality, previous experiences of CPs can also reinforce the perceptions regarding the high costs of using RCMs. IP23-A explained this relationship between prior experiences and perceptions regarding high costs as follows, "*Quite often, there'll be some pre…kind of, yeah, previous experience, where they've had a really high cost associated with it, so they just don't look at it again*." Overall, these findings indicate that perceptions regarding the high costs of RCMs limit their uptake, which suggests the need for an attitudinal shift to promote the uptake of these materials among CPs.

4.3.1.2 Personal capabilities

Personal capabilities refer to the knowledge and skills required and the availability of other general capabilities and resources, which determine one's ability to engage in pro-environmental behaviours. The lack of such capabilities can, therefore, limit the performance of pro-environmental behaviours. The findings identified two such lapses in the capabilities of CPs that limit the uptake of RCMs: (1) lack of knowledge and skills required for using RCMs and (2) limited time available to consider RCMs during the material selection process. These factors are explained in detail in the following sections.

4.3.1.2.1 Lack of knowledge and skills required for using RCMs

The study findings highlighted an apparent lack of knowledge and skills required for using RCMs among CPs. During the interviews, the participants were questioned about the level of understanding among CPs regarding RCMs. In response, IP13-E commented that CPs are not as knowledgeable as they probably could be. Similarly, IP25-C pointed out that although some professionals are aware of RCMs and their uses, there would not be a higher level of understanding for every person in the industry. Furthermore, IP17-A noted that working with RCMs requires additional knowledge about these materials, such as their potential applications, performance levels, and other specificities that differentiate them from their virgin counterparts. The interviewee asserted that not all CPs would have acquired this knowledge, thus limiting them from considering RCMs during material selection. IP18-A went on to highlight this as a notable shortcoming on the part of CPs responsible for advising clients on the different material options available. As emphasised by IP18-A,

> We have a responsibility to at least educate our clients to say that these are options for consideration, and if they are a client that cares about those sorts of things, invariably they are more likely to take that on.

If CPs themselves are unaware of RCMs, clients are unlikely to be exposed to these materials unless in the case of a knowledgeable client with prior experience.

Lack of knowledge was recognised as more of a problem among builders, primarily due to the lack of training around concepts such as sustainability and material efficiency available for builders. This was evident from the following comment by IP12-C from a contracting background, who explained that only those builders interested in alternative material solutions would, therefore, amass knowledge in these areas.

> There's not enough training of builders. So, builders that are not otherwise self-interested in following a path of material efficiency or sustainability, they won't, yeah, they won't come to it on their own on mass because the training is not provided.

Alternatively, education programs for architects and engineers were found to have increasingly incorporated sustainability aspects into the learning outcomes. Therefore, these professionals were seen as relatively more aware of RCMs when compared to builders. This was affirmed by IP3-A, who had prior experience in academia. The interviewee highlighted that architecture students are taught about areas such as managing embodied energy and carbon footprint, which are topics closely related to the use of RCMs. Similarly, IP8-E opined that there are also growing opportunities for engineers to become trained in areas related to green construction. The interviewees further expressed that builders might also need to develop specialised skills when working with RCMs. Herein, IP12-C highlighted one such example of the skill of selecting timber suitable for reprocessing from timber that should be cut off into firewood or discarded due to termite damage.

Despite the identified lapses in knowledge and skills, IP11-C observed an increase in the efforts among CPs to become more knowledgeable about RCMs rather than in the past, where these materials were mostly rejected outright without any research into their use. This is highlighted through the following comment by the interviewee:

> The industry is getting more knowledgeable about it, you know, getting a little bit smarter about how they don't just say 'no, we are not going to do it,' you know. At least they say, 'we'll do a little bit of research, we'll see what's available, we'll see how usable, and, you know, if there's any project impacts', and they'll come back with a little bit more knowledge of it.

The above findings suggest the need for strategies to impart CPs with the knowledge and skills required for using these materials.

4.3.1.2.2 Limited time available to consider RCMs during the material selection process

Construction projects are highly time-constrained endeavours. Clients increasingly want their projects to be completed within the shortest timeframe possible. As affirmed by IP26-C, "*Project timelines are decreasing, and clients are wanting more and more in less time.*" Therefore, CPs are constantly pressured to complete projects within very short timeframes. According to IP11-C, the inability to deliver a project within the expected timeline can carry heavy penalties, especially for builders, and therefore, anything that might inhibit the programme would not be considered favourably. Further, IP18-A mentioned that CPs generally handle multiple projects at any given time and are, therefore, extremely time-poor. Due to such time constraints, CPs have limited time to consider RCMs during material selection.

Due to their novelty, more research is needed when using RCMs to identify what reprocessed options are available in the market and to ensure that they meet the expected standards and codes. This can be a time-consuming process. As IP4-A commented,

> There would be more research and cross-checking that would be involved in terms of us making sure that we're specifying products that are to code; yeah, it does, it takes more time than an off-the-shelf new product…it's a specialist product, it's not something that's used as much as new.

Similarly, IP23-A mentioned, "*It's definitely more time-consuming because we have to research and verify that it meets the requirements*." The interviewees also asserted that information about RCMs is not readily available and well organised, and multiple suppliers would, therefore, have to be contacted to get the required information, which is a time-intensive exercise. Therefore, off-the-shelf virgin materials are preferred by CPs to capitalise on the limited time available.

The interviewees emphasised that time limitations are more of a problem in fast-paced commercial construction projects driven by the urge to capitalise on market opportunities and to recoup the investments made as quickly as possible. However, there can be greater flexibility around timelines in residential projects, thus allowing more opportunities to use RCMs in such projects. As explicated by IP15-C,

> Residential maybe a little bit different, where a client might be willing to wait. But you're not going to find that in the commercial world, yeah, particularly now, with the fast-paced nature of commercial construction.

Similarly, IP11-C noted that there could be more opportunities for RCMs in government projects with flexible timelines and no time-related penalties.

The findings resonated that if information regarding RCMs is readily available and can be accessed quickly, it can minimise the time needed to determine the feasibility of using these materials upfront, which can promote their use.

4.3.1.3 Habits or routines

Under habits or routines, the study findings identified the tendency among CPs to gravitate towards regularly used materials as a factor that can limit the uptake of RCMs. This has been explained in detail below.

4.3.1.3.1 The tendency among CPs to gravitate towards routinely used materials

When making decisions around materiality, CPs do not always go to the first principles and start everything anew. Following a more naturalistic decision-making approach, they base their decisions on previous experiences and select materials that have worked in the past. As these materials were selected repetitively, using them has become common practice. Consequently, CPs tend to gravitate towards these materials rather than consider other alternatives, thus limiting the virgin-to-reprocessed shift. As commented by IP5-A, "*People have products that they've used before, so they sort of tend to gravitate towards those*." IP17-A alluded to this notion and highlighted that CPs generally cycle through a small group of materials used repeatedly, albeit in different ways. Although new material options might be considered under certain situations (for instance, based on the requirements of a client for a specific project), CPs will revert to the regular materials shortly afterwards. IP8-E elaborated on this as follows:

> It's [the use of RCMs] always…it's one of those things which few key people will enforce it, and it's done on a couple of projects…And then, it starts to go back to the old ways, yeah, within, you know, a short time after that.

IP8-E argued that changing these habits or routines is more difficult among CPs who have been in the industry for a long time and are "*entrenched in their ways* (IP8-E)". Moreover, new professionals entering the industry are likely to be influenced by these tendencies since they look to seasoned professionals for guidance and advice. As IP8-E put it:

> They [new professionals entering the industry] are just taking note from these seniors set in their ways, so yeah, 'I'll just do it how Big Tony's always done it, he's done all right, he's okay', and yeah, ultimately, it comes down to it.

The routine selection of materials is sustained by relationships between CPs and material suppliers. As highlighted by the interviewees, most CPs have established relationships with material suppliers who predominantly supply virgin materials. These arrangements can be around costs, time, and delivery and sometimes include rewards for recommending

materials from a specific supplier (IP11-C). Consequently, CPs resort to materials from such suppliers by default and rarely look for outside alternatives. This limits the possibility for RCMs to enter the material mix. IP4-A commented on this issue as follows:

> So, they might have arrangements with certain trades or certain companies where they get cheaper products in return for using the same person all the time. So, they always have their go-to group of people, and if it's anything outside that, they'll always push back.

It is worth mentioning that routine decisions around materiality are prominent among builders engaged in the volume housing industry, where there is much repetitive work. IP7-E stressed this point as follows:

> Builders, they're very much a cookie-cutter-rinse-repeat sort of approach to construction. A lot of their trades are used to the same, working with the same materials, doing the same thing. So, there's a lot of that rinse and repeat in that side of the volume industry.

4.3.2 Contextual factors limiting the uptake of reprocessed construction materials among construction professionals

Pro-environmental behaviours have external conditions associated with them, which are referred to as contextual factors. A multitude of such contextual factors that can potentially limit the uptake of RCMs among CPs was identified through the interview findings. Since contextual factors cover a broad spectrum, they were further classified under six sub-categories: (1) client-related factors, (2) organisation-related factors, (3) cost-related factors, (4) quality-related factors, (5) availability-related factors, and (6) regulatory environment-related factors. A summary of these factors is shown in Figure 4.2, with detailed explanations presented in the following sections.

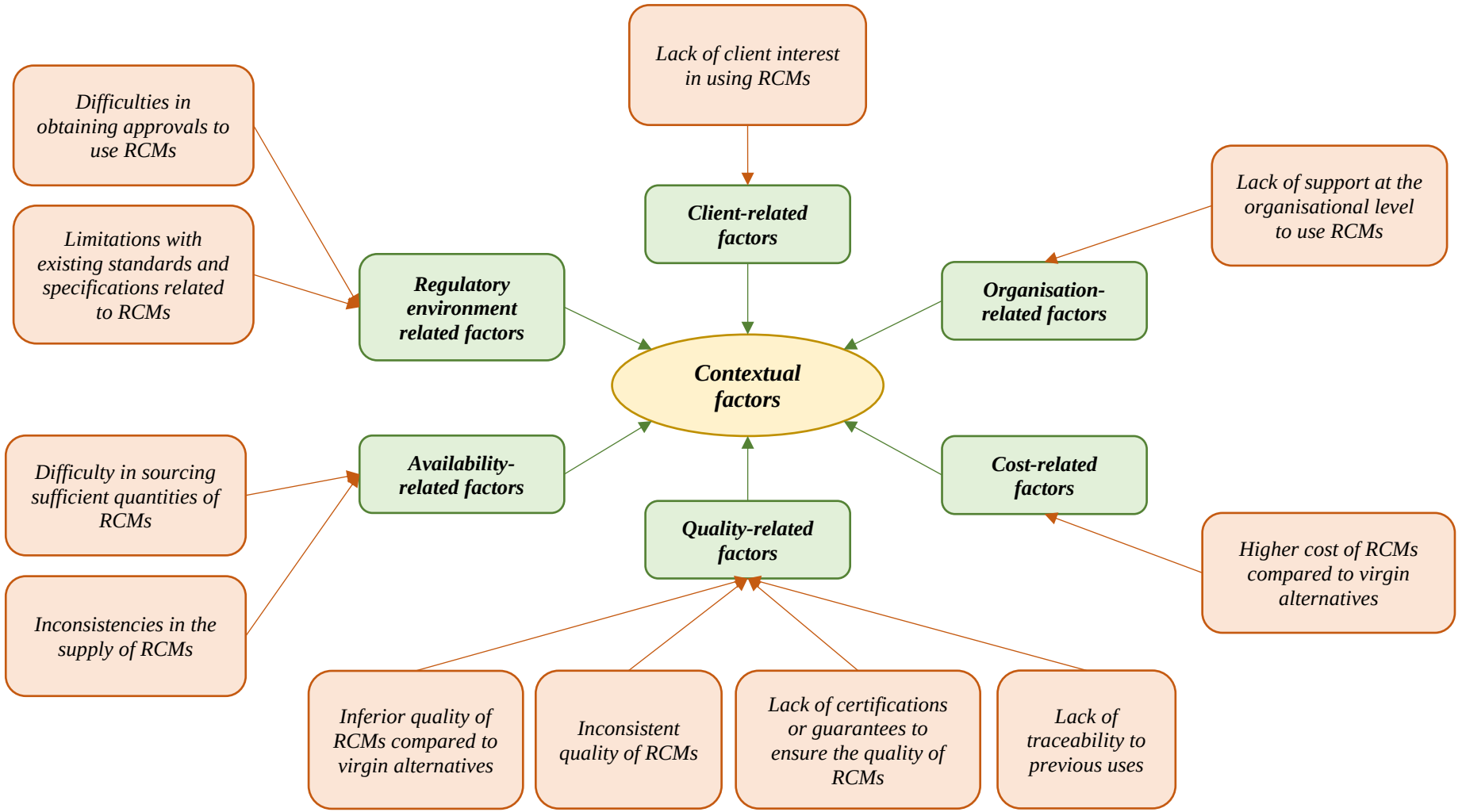


Figure 4.2: Summary of contextual factors that limit the uptake of reprocessed construction materials among construction professionals

4.3.2.1 Client-related factors

As the initiators and financiers of construction projects, clients can have a strong influence on the decisions made by CPs. Consequently, the lack of interest among clients in using RCMs was identified as a factor that can limit the uptake of RCMs among CPs.

4.3.2.1.1 Lack of client interest in using RCMs

With ultimate project decisions being centred around client requirements, client interest can go a long way in facilitating CPs to use RCMs. However, most clients were seen as uninterested in using RCMs, which has limited CPs from considering these materials. As commented by IP5-A, "*It depends on the client at the end of the day… it really matters what type of clients you've got and how open they are to that conversation*." Adding to this, IP19-A mentioned, "*It's not common that people request for these kinds of things to happen… if the client is not ready to commit, it's hard to bring into that end*." As pointed out by IP21-A, apart from a few who are educated and care about sustainability, most clients are not interested in using RCMs.

The study findings found that clients are primarily motivated by cost considerations. Most client decisions are based on cost-benefit, while sustainability aspects such as using RCMs are rarely considered. "*Clients need to get the best value for dollar, and so, the environmental considerations can take a bit of a second place*", said IP1-E. Therefore, unless RCMs offer a financial advantage over virgin materials, clients would rarely be interested in using them. This cost-focused decision-making of clients was highlighted through the following comment by IP3-A:

> If the performance criteria and the intent of the building can be met with standard materials, but it would cost more and break the budget by using reprocessed materials, I dare say the inclination will be to substitute it to a new material.

Consequently, CPs face the hurdle of convincing clients to see things in a sustainability framework rather than a dollar-and-cents framework.

In the current context, using RCMs can, in fact, be associated with higher costs (explained in more detail under Section 4.3.2.3.1). This makes RCMs less attractive to cost-conscious clients. Therefore, RCMs are often replaced with low-cost, virgin alternatives in the efforts to bring down project costs to align with client budgets; "*It's often the first bit that comes off when you are trying to get the price down,"* said IP14-C. IP4-A recalled one of her previous project experiences where reprocessed bricks were replaced with virgin bricks primarily because of the client's focus on cost minimisation:

> I've worked on a lot of childcare centres, and our…one of our main clients was a big developer. They just kind of wanted to get a bent buck. So, we did actually suggest some reclaimed bricks for a feature wall in a project, and yet, cost came down to it, and they said, 'just specify a new brick product'. So, that's what happened in that project. It was this…this new brick product is going to be cheaper, so just pretty much pick a colour from that."

Furthermore, IP16-C mentioned that clients select builders on a minimum-cost basis without much consideration for the ethical stance of the builder on using RCMs. Therefore, builders that propose RCMs that are more expensive than virgin materials would lose out on the opportunity to win projects, despite offering better environmental outcomes. Consequently, even those builders with an environmental focus have to give up on their values and offer low-cost, less-environmental-friendly options to survive in the market.

Despite clients saying that they are happy to use RCMs, when push comes to shove, and they actually have to pay more to get those materials, they tend to default on their word. Elaborating on this, IP15-C expressed, "*I'm sure everyone will say they are happy to use it, but are they happy to pay more for it? That's probably the big question in this day and age.*" This was complemented by IP21-A, who mentioned, "*People like the idea of being green, but yeah, to really commit to it and economically pay more, that's when you start to work out how committed people are really.*" Study findings also repeatedly suggested that convincing commercial clients like large developers to use RCMs is more challenging due to their money-driven nature and reluctance to do things differently. As stated by IP5-A, "*Normally, when you talk to big developers, they are all about the new and yeah, they don't want to hear recycled.* IP7-E and IP11-C commented that commercial clients do not have any emotional attachment to the project, and they simply want to build, sell, make a profit, and move on, and CPs, therefore, have fewer opportunities to consider RCMs in such settings.

In summary, the findings highlighted that CPs would not consider using RCMs unless they have clients who support such decisions. As affirmed by IP17-A, "*You really need a client who wants some of these things or has a certain lean towards being, you know, more environmentally aware.*"

4.3.2.2 Organisation-related factors

Under organisation-related factors, the lack of support at the level of design and construction organisations to use RCMs was found to limit the uptake of these materials among CPs.

4.3.2.2.1 Lack of support at the organisational level to use RCMs

The uptake of RCMs among CPs can depend on the practices and procedures of the design and construction organisations in which they are employed. As stated by IP4-A, "*It* [the use of RCMs] *depends on the practice and their methodology.*" IP1-E further asserted that support from entrepreneurial-type managers who can see the opportunities for RCMs is needed to broad-base the use of these materials within organisations. The study findings highlighted a lack of such support at the organisational level in enabling the use of RCMs, which has demotivated CPs from considering these materials. IP10-E commented, "*If we are trying to make progress, but there's no direction from the top of the company, yeah, it can be frustrating*." IP2-E, IP8-E, and IP10-E emphasised that even though individual professionals might prefer to use RCMs, they are limited by a lack of support at the organisational level to proceed further. On the contrary, IP5-A, IP12-C, IP13-E, and IP19-A noted that some organisations promote green design and sustainable construction and support initiatives to use RCMs. However, such initiatives are not mainstream yet.

4.3.2.3 Cost-related factors

Cost is an important consideration for CPs in material selection since they have to work within the constraints of the client's budget. Moreover, builders specifically have to offer lower prices to remain competitive in the market whilst retaining sufficient margins to ensure business viability. Within such a background, the findings highlighted that the higher cost of RCMs compared to virgin alternatives can limit the uptake of these materials among CPs.

4.3.2.3.1 Higher cost of RCMs compared to virgin alternatives

The interview findings echoed that RCMs, in general, are costlier than virgin alternatives, which makes it challenging to use these materials. As noted by IP8-E, "*To be truthful, generally, there is a premium associated with these materials* [RCMs]." Adding to this, IP19-A mentioned, "*They* [RCMs] *are still more expensive than standard materials, so that doesn't make it easy to introduce them into a project.*" Therefore, IP16-C asserted that if the project costs exceed the client's budget, any expensive RCMs will be replaced with cheaper virgin alternatives to bring down the costs. As elaborated by the interviewee,

> In construction, what often happens is the architect draws the building, and it kind of gets priced, and it might be over budget. So, we have to start pulling things out to get the price down to the client's request. Now, if you've got an expensive reprocessed material and it can be replaced with a new material for cheaper, it'll obviously be replaced to get the cost down.

Based on prior experiences with using RCMs, the interviewees noted that RCMs like bricks and timber are more expensive than their virgin counterparts. IP15-C recalled an example of a previous project that had used reprocessed timber columns and beams as an architectural feature, where the reprocessed timber used had been more expensive than virgin timber:

> We had a job, we didn't have a large quantity, but we had some big feature timber columns and beams, and we had to source them. That was definitely more expensive, so yeah, we certainly paid a premium over new timber, and it cost us a lot more than what we expected it to be.

This was further affirmed by IP11-C, who mentioned that he had come across instances where the cost of reprocessed timber was as high as four times the cost of virgin timber. Likewise, IP21-A noted that reprocessed bricks could also be 50-100% more expensive than virgin bricks. As stated by the interviewee:

> We've used a number of recycled red bricks, but if you were to buy recycled red bricks from a salvage company [waste processor], it's 50% to 100% more expensive than just buying normal red bricks from Company X [Original company name mentioned by the interviewee was removed for confidentiality reasons].

The high cost of reprocessed bricks was also acknowledged by IP14-C, who had sourced red bricks for a rustic feature wall in a bar, where the bricks had cost 70-80% more than virgin red bricks. Because of these high costs, CPs primarily use RCMs as architectural features to benefit from their unique appearance and when the quantity required is low, as in the abovementioned examples, so that the overall impact on the project costs is low.

Interestingly, several interviewees noted that recent years had seen the development of virgin materials that look like RCMs. These materials offer a resemblance to RCMs in terms of aesthetics and texture but at a lower cost. This enables achieving the desired visual attributes of RCMs without incurring the higher costs linked to procuring actual RCMs. IP11-C elaborated on this as follows, using the example of virgin bricks, which are made to look like reprocessed bricks:

> We are actually now seeing brick suppliers reinventing bricks to look like old bricks. So, they could actually do that cheaper now, in designing a brick that looks like an old brick, cheaper than they can get a recycled brick…so, it's not a great thing, I don't think, but it obviously gives the look of a recycled product.

Such industry developments have deteriorated the popularity of RCMs, especially among architects, who prefer the unique appearance of RCMs.

The interviewees highlighted several possible reasons for the high costs of RCMs, the chief among which is the labour-intensiveness of the waste recovery process. Recovering materials from an end-of-life structure requires more labour for manual dismantling, separating, reprocessing, and making the materials sale-ready. With high labour rates in Australia, these labour-intensive processes can become costly, which is reflected in the price of some RCMs. IP16-C elaborated on the labour-intensive nature of the waste recovery process by citing the example of recovering bricks from an end-of-life structure as follows:

> It's just for the labour cost of actually recycling. So, like reusing bricks, you have the demolition cost, you have the cleaning cost, the repacking cost, whereas a new brick is straight out the kiln, fresh bricks sort of thing. Let's take a house, for example, you know, to actually salvage the bricks and use them, you almost have to knock them down by hand, so you're not going to smash them up; that's an extra cost. Then they have to be cleaned up by hand to get the mortar off them. Then you have to pay someone to restack them on pallets and get them back out. So, there's so much more cost than building a new one.

As noted by IP11-C, the same applies to recovering timber, and in addition, timber must be de-nailed, reshaped and thickened to meet market requirements. This additional processing would ultimately affect the cost of reprocessed timber, potentially making it more expensive than virgin timber. Another reason for the high costs could be the requirement for specialised technologies in waste recovery. For example, IP24-A expressed that reprocessing timber might require advanced metal detection systems to identify concealed fixings that could otherwise damage equipment such as saw blades. Finally, IP12-C, IP13-E, and IP15-C expressed that the lack of economies of scale in reprocessing and high transportation costs could also be reasons for the high cost of RCMs. These findings suggest that encouraging the use of RCMs requires strategies to make these materials more cost-competitive when compared to virgin alternatives.

4.3.2.4 Quality-related factors

Ensuring project quality is among the primary responsibilities of CPs, and therefore, quality is a key criterion considered in material selection. Hence, quality issues can demotivate CPs from using RCMs over virgin alternatives. The study findings identified multiple quality-related factors that can limit the uptake of RCMs among CPs, which include (1) inferior quality of RCMs compared to virgin alternatives, (2) inconsistent quality of RCMs, (3) lack of certifications or guarantees to ensure the quality of RCMs, and (4) lack of traceability to previous uses.

4.3.2.4.1 Inferior quality of RCMs compared to virgin alternatives

The study findings reverberated that the quality of RCMs can be inferior compared to virgin alternatives. The interviewees pointed out multiple occasions where they had encountered issues with the inferior quality of different RCMs like timber, bricks, aggregates, metals, and landscaping materials. Elaborating on the inferior quality of reprocessed timber, IP16-C recalled his previous experience with fractured structural timber members, which had to be discarded owing to the risk of structural failure. IP24-A also highlighted his experience with reprocessed timber having concealed nails and fixings that damaged builders' equipment. Similarly, IP31-C noted some situations where reprocessed timber members had been contaminated with lead-based paints and chemicals such as Copper-Chrome-Arsenate (CCA), which are toxic. IP3-A, IP11-C, IP16-C, and IP24-A noted similar quality failures with reprocessed bricks, where they encountered fractured bricks, which might have been damaged during dismantling and showed poor stability. Quality issues were also reported with recycled concrete aggregates (RCAs) used as fill materials (e.g., as road base and under building foundations) (IP1-E, IP2-E, IP12-C, and IP22-E) and as aggregate replacements in concrete mixes (IP21-A), where they were contaminated with foreign materials. For example, IP1-E elaborated on a quality failure associated with using RCAs for a road base as follows:

> We had a base course put down with recycled materials. In the recycled materials, there was some aluminium. The aluminium gets wet, and then it effervescence and expands, and so, we've had to fix up the asphalt because it just ballooned up and blew the asphalt apart. So yeah, that was a recycled material where some of the contaminants didn't get removed because they weren't magnetic [i.e., contaminated with aluminium].

Moreover, IP11-C mentioned that he had witnessed some recycled steel whose tensile strength was not comparable to that of virgin steel, and both IP13-E and IP23-A highlighted their prior experiences with poor-quality landscaping materials like pavers and mulches contaminated with foreign matter.

The interviewees noted that quality failures with RCMs can result in multiple problems, such as high levels of wastage, increased material requirements, and the need for rectifications, which can all lead to higher project costs. IP11-C elaborated on the problems associated with higher wastage and resulting higher costs through the example of reprocessed bricks as follows:

> Things like bricks, which I was mentioning to you about the stability of second-hand bricks, you can't guarantee it. It has been used before, it's demolished, and when it was demolished, it may have caused fractures in the structure of the

> bricks. So, you might throw every third brick if we come along a crack, and, you know, there's going to be a certain amount of wastage; it's going to cost us more.

Likewise, IP11-C and IP15-C emphasised that the oversizing of building elements and additional support mechanisms would have to be considered to compensate for potential quality failures with RCMs, thus requiring more materials. Herein, IP15-C recalled an example where reprocessed structural timber columns had been oversized to account for possible deformities in the timber:

> The columns, they were actually structural columns…the engineer had oversized them considerably, so even if they had big deformities or so forth in them, they'd still be within the structural requirements to do the job on hand.

A similar example with reprocessed bricks was also noted by IP11-C, where secondary framing had to be used as a support mechanism for a reprocessed brick wall in a multi-storey building. Furthermore, IP1-E, IP2-E, IP16-C, and IP21-A flagged the complex and costly rectifications that would have to be undertaken in the case of quality failures with RCMs. For example, the following extract from the interview with IP21-A outlined in detail a quality failure with RCAs used as a virgin aggregate replacement in a polished concrete slab that resulted in high rectification costs:

> So, we had used recycled aggregates in concrete some time back…So, we had that done and grounded it all down to three, four mils [millimetres], full grind, polished it, and it was quite interesting because all sorts of stuff found its way in, little bits of metal, bark chips, little bits of polystyrene, and all of those things were exposed. And so, some of those things, like the bark chips and polystyrene, came out and left holes in the polished concrete alright…So, the builder had to get the flooring contractor back to get the grout to try and match the colour of the concrete and grout all of these little holes everywhere. So, all of a sudden, the recycled aggregates cost more because of these problems."

The findings echoed that unless RCMs are of comparable quality to virgin alternatives, they are less likely to be used.

4.3.2.4.2 Inconsistent quality of RCMs

The study findings highlighted that, unlike virgin materials, there could be a higher level of inconsistency associated with the quality of RCMs. Such inconsistencies in quality inhibit CPs from using RCMs. The following statement by IP3-A clearly emphasised this issue through the example of reprocessed bricks:

> If I test ten bricks that are recycled and ten that are new, the new ones have a level of continuity and consistency about them. But if I test ten recycled bricks, is the eleventh one going to be the same, is the twelfth one going to be the same…I cannot be sure.

IP19-A noted a real-life example of reprocessed bricks of inconsistent quality, where she had difficulty matching bricks for a reprocessed brick wall due to significant variations in the appearance of the bricks. IP21-A also recalled similar experiences with using reprocessed bricks. Likewise, IP12-C mentioned that he had come across batches of reprocessed timber floorboards of different widths, which required more time to separate before fixing and affected the visual quality of the finished floor due to the differences in the widths being used. Furthermore, IP13-E highlighted situations where inconsistencies were noted with the quality of RCAs as well.

The interviewees noted that with virgin materials, one could select a particular material and get that exact material from the market. However, that might not be possible with RCMs due to the inconsistencies in their quality; "*They* [RCMs] *might come out, and they might not be exactly what you want,*" said IP16-C. The following extract from the interview with IP21-A further flagged this issue:

> With new materials, you can point at something and go, that's the material, that's the brick wall, go down to the brickyard, and so that's exactly what it's going to look like. But with reprocessed stuff, hmm… it might not be the case. So, we have actually had a few jobs where we've specified recycled red bricks, and the brickies [brick layers] put them up, and the clients have gone, you know, like, 'Oh, I didn't think they'd look that rough'. So, we run that risk.

The above extract shows that clients can be unsatisfied when the finished product does not match what was expected, which can reflect negatively on the CPs who selected the materials. Therefore, it can inhibit CPs from considering RCMs.

IP1-E, IP11-C, IP13-E, and IP24-A recognised the variety of input sources used in manufacturing RCMs as an underlying reason for the inconsistent quality of these materials. For example, IP1-E commented, "*Reprocessed materials can come from anywhere and from any use and could be contaminated in a whole host of ways.*" Similarly, IP13-E added, "*that* [RCMs] *can come from a variety of demolition jobs, and so, it will be less consistent.*" IP22-E also recognised the lack of standards and specifications for RCMs (explained in more detail under Section 4.3.2.6.1) as another possible reason for the inconsistent quality of these materials since this means that suppliers do not have a benchmark against which their materials can be compared.

4.3.2.4.3 Lack of certifications or guarantees to ensure the quality of RCMs

The lack of certifications or guarantees for ensuring the quality of RCMs was identified as another quality-related factor that limits the uptake of RCMs among CPs. Without the required certifications or guarantees, CPs cannot ascertain whether the quality of RCMs is

comparable to that of virgin alternatives or whether the material is suitable for the specific application at hand. Due to such uncertainties, CPs tend to steer away from RCMs. As stated by IP8-E,

> The industry won't use them [RCMs] unless they come with certifications or guarantees; it's as simple as that. So, we need to make sure that we're providing our client with like for like and giving them the security that something we are specifying and something they are putting in their building or on the building is equal to [virgin] from a quality or performance perspective as a minimum.

Selecting RCMs without the required certifications or guarantees is an added risk for CPs because if any quality failures do materialise, they will ultimately be held liable for selecting materials whose quality is not certified or guaranteed. As expressed by IP3-A, if there is a quality failure, people will first come after the specifier for choosing materials without certifications or guarantees.

Moreover, quality certificates or guarantees are crucial in ensuring that the materials specified comply with the current regulations, standards, and codes and meet the relevant insurance requirements. For example, IP11-C noted a strong emphasis on the combustibility of different façade materials following recent fires in several high-rise buildings in Melbourne. Consequently, if there is no certification or guarantee to prove that RCMs can meet the expected fire ratings, CPs cannot select such materials for similar applications. IP6-A, IP11-C, and IP17-A further highlighted that compliance issues are more of a problem in commercial settings where stricter compliance requirements apply. Similarly, IP5-A added that insurance companies would consider quality certificates or guarantees before checking off on projects and determining insurance premiums.

The lack of quality certifications or guarantees also means that additional testing will have to be undertaken when using RCMs to ensure that these materials are suitable to meet project requirements, which adds to project times and costs. The following example by IP21-A on the use of reprocessed timber for a structural application highlighted this issue:

> If you use recycled stuff, then you've got to get, you know, particularly if its timber being used for an engineered solution, so, it's got a span. We've got to get an engineer out there to have a look at it, get it certified…I did a few jobs where we used exposed rafters, recycled timber rafters, for pergolas and that sort of thing, and for [the] inside of a raked ceiling area. So, we used 600, a nice big rafter, and yeah, it was more of a hassle to get the engineer to certify that, make sure that it's going to stand up…I mean, that process takes longer and costs a bit more to get that done."

These findings emphasised that CPs need to be assured of the quality of RCMs through certifications or guarantees to improve their uptake.

4.3.2.4.4 Lack of traceability to previous uses

The interviewees identified the lack of traceability to previous uses as another quality-related factor that deters CPs from using RCMs. "*Chain of custody… where things are coming from, that's where we're not seeing a lot of open discussions around*," said IP11-C. Traceability is vital since the previous uses of RCMs can determine how these materials are used for new applications. Using the example of timber, IP11-C and IP29-C explained that the strength of reprocessed timber can depend on the loads previously held by it. As expressed by IP29-C, "*Users would be concerned with the effect of previous life loads on its integrity going forward*." Therefore, if the timber has borne heavy loads in its previous life and has suffered damage, it would not be suitable to reuse it in a structural application. IP11-C further noted that whether a piece of timber had been used for an internal or an external application and the resulting exposure to the natural elements can also determine its secondary use. IP11-C elaborated on this point as follows:

> Anything that's been exposed to the marine would have been exposed to the extremes of weather, whereas if it was an old factory and it was a roof beam that's been inside for 100 years, and then you are going to use it externally, then it maybe compromised.

This internal-external distinction can also become necessary when using reprocessed bricks, where bricks originally used for internal applications might not be suitable for external applications. IP24-A stressed this point as follows:

> You have to be very careful you get a suitable external grade. Now, for example, bricks, historically, you had bricks that were used externally. They tended to be the harder, more durable bricks because of the way they were fired. But, as part of that process, there were often softer bricks that were not fired as well. So, they were generally used internally on internal walls and things like that. So, you have to be careful that if you're using in an external application, you're using a brick that was intended to be used externally, not one that was intended to be used internally.

Unless RCMs can be traced to their previous uses, such a distinction cannot be made and thus can potentially lead to future quality failures. Traceability to previous uses also helps CPs understand the possibility of harmful contaminants being present in RCMs so that such materials can be avoided. For example, IP16-C noted that if materials are recovered from a location where contaminants can potentially be present, like a pesticide factory, CPs can avoid using such materials that can leach harmful contaminants and pose a threat to users. The findings emphasised that the lack of traceability to previous uses can raise questions regarding the quality of RCMs, thus limiting their use among CPs.

4.3.2.5 Availability-related factors

The interview findings emphasised that limitations in the availability of RCMs can inhibit CPs from using such materials. Herein, (1) difficulty in sourcing sufficient quantities and (2) supply inconsistencies were identified as availability-related factors limiting the uptake of RCMs.

4.3.2.5.1 Difficulty in sourcing sufficient quantities of RCMs

Multiple interviewees stressed that the difficulty in sourcing sufficient quantities of RCMs to meet project requirements had discouraged CPs from pursuing these materials. As expressed by IP16-C:

> There's no readily available amounts of certain products; so, you know, you can go to Company X [Original company name mentioned by the interviewee was removed for confidentiality reasons] and get red bricks, but you can't be sure if the same quantity is going to be available in reprocessed bricks.

IP19-A added that not many suppliers are capable of supplying reasonable quantities of RCMs and that it is a reason commonly cited by many builders and subcontractors for not using these materials. Consequently, RCMs will simply be replaced by virgin alternatives, which are available in abundance. Such limitations with the available quantities have made the use of RCMs unviable, especially in large-scale projects with high material requirements. As expressed by IP5-A, "*Once you get to the large-scale projects…reprocessed materials are quite hard to get at such large quantities*." Adding to this, IP15-C mentioned, "*It comes down to the quantities that you need; if you need too much, it's too hard to find*." Within such a context, CPs would have to contact multiple suppliers to source the required quantities of materials, which can be time-consuming. Moreover, sourcing materials from multiple suppliers located at different sites can also increase transportation costs, especially with Australia's rising fuel and labour costs. As noted by IP8-E:

> When you start running trucks, you have to put that into account as well; running, you know, ten trucks for two weeks, that's a huge cost, and if you can save 10-20 kilometres, you'll save so much more money.

Similarly, the interviewee highlighted that it can lead to high transportation-related emissions, thus offsetting the environmental benefits of using RCMs.

The findings asserted that these quantity limitations could be traced back to the availability of DW, which can be reprocessed. Unlike virgin materials, sufficient quantities of RCMs cannot be made available readily unless there is an organised inflow of waste materials for

reprocessing. This was affirmed through the following extract from the interview with IP15-C:

> If you want new bricks, you can just go order them, [and] you know you are going to get them in six weeks' time because they are going to make them for you. If you want, you know, a thousand square meters of recycled bricks, they will say, 'Ah! We've only got 500 at the moment'…They need to have reclaimed those bricks from somewhere…If they haven't demo'd [demolished] any buildings that have got nice red bricks, then well, they've got none to supply.

The dependence of supply on the availability of recoverable DW also means there are difficulties in sourcing RCMs that exactly meet project requirements. For example, IP30-C stated that whilst an engineer's drawing might specify the dimensions for a specific piece of timber based on the structural requirements, it can be difficult to match those exact dimensions unless a structure with similar timber elements has been dismantled. Interviewees further acknowledged that the difficulties in sourcing sufficient quantities of RCMs could be aggravated by limited supply sources available for these materials. IP13-E and IP22-E expressed that this can be more of a problem in regional areas with limited suppliers of RCMs.

4.3.2.5.2 Inconsistencies in the supply of RCMs

The study findings reiterated that there are inconsistencies in the supplies of RCMs, which makes it difficult to source these materials as and when required. Furthermore, there is no certainty over when these materials would become available for purchase; "*It can vary at various times, what's available, what isn't,*" said IP24-A. IP15-C elaborated on this issue by recalling an example of a project where he faced problems due to inconsistencies in the supply of reprocessed timber:

> There are ebbs and flows in supplies. That was a problem with the [reprocessed] timber. When we quoted the job, we could source this timber, we had it all priced, we knew who we were going to get it from. Then, by the time we ordered the timber [the supplier had replied], 'Oh no, sorry, I don't have it anymore. Don't know if I'll ever get any more of it'. So, there's certainly an issue with the supply; there's no guaranteed supply.

Such inconsistencies in the supply of RCMs introduce a higher degree of uncertainty into the material sourcing process, which demotivates CPs from using these materials. Similar to the shortfalls in quantities, the findings related supply inconsistencies to limitations with the availability of waste materials for reprocessing. As expressed by IP29-C, "*There would be inconsistencies with supply as the amount of reprocessed materials available would depend on the amount of demo* [demolition] *jobs which have suitable materials for reuse*."

4.3.2.6 Regulatory environment-related factors

Interview findings emphasised that factors related to the regulatory environment can also inhibit CPs from pursuing RCMs. Accordingly, such factors include (1) limitations with existing standards and specifications related to RCMs and (2) difficulties in obtaining approvals to use RCMs.

4.3.2.6.1 Limitations with existing standards and specifications related to RCMs

The findings revealed that existing standards and specifications do not adequately cover RCMs. Standards and specifications ensure consistency in quality, safety, and performance across built facilities and highlight the requirements to be met by construction materials used for specific applications. These documents outline what materials can be used for a given application and their quantities, properties, and performance levels. "*It really comes down to the standards and specifications; that drives what we can do and what we can't do*," said IP22-E. Therefore, without clear standards and specifications, CPs cannot determine the suitability of RCMs for specific applications, thus limiting their use. For instance, IP1-E noted that without the required specifications, they are unable to determine consistent replacement levels for virgin materials in material mixtures (i.e., the volume of virgin materials that can be replaced by RCMs in material mixtures such as concrete with recycled aggregates or recycled road base), which can lead to inconsistencies in the performance of end products. IP27-A also added that some specifications, such as those used by water authorities in New South Wales (NSW) and Victoria, are outdated and, therefore, do not have provisions for using RCMs. Owing to such limitations with the standards and specifications, the interviewees noted that they have to assess RCMs against the standards and specifications for virgin materials, which might not be befitting since they do not capture the specificities related to RCMs and contain more stringent requirements that RCMs cannot reasonably meet. IP1-E, IP16-C, and IP22-E further noted that some standards and specifications explicitly exclude the use of RCMs, and in such cases, they have no option but to go with virgin materials. As expressed by IP16-C:

> The government doesn't allow it; the specifications actually say all new materials…when requirements are not to use reprocessed materials, their [CPs'] hands are tied, so they can't specify that sort of products.

While some specifications have been developed for RCMs used in infrastructure applications (e.g., recycled road base), they have been developed by individual state and territory governments and lack universal application across Australia. IP1-E, IP8-E, and IP13-E noted that such specification inconsistencies hinder the use of RCMs, mainly when

material movements occur across state borders. This is because materials processed to the specifications of one state might not be accepted in another. IP13-E emphasised this point as follows:

> So, our Environmental Protection Authority [South Australian Environment Protection Authority] would have different specifications to every other state and territory's Environmental Protection Authority. That was one of the issues that we came across with [the] Austroads project…and the idea [with the Austroads project] is to create a nationally consistent sort of specifications that all road jurisdictions can adopt. But one of the problems that we ran into, you know, when Austroads developed the chemical criteria for recycled pavements, the upper limits for different contaminants, they developed that based on the New South Wales EPA criteria, and our EPA wouldn't accept it…So, yeah, that's an issue; it just makes it, you know, more complicated.

Interestingly, feedback from IP2-E and IP16-C suggests that there can even be inconsistencies in specifications developed by government bodies within the same state or territory. For example, IP16-C mentioned that in South Australia, although the Department for Infrastructure and Transport (DIT) specifications include provisions for using RCMs in road pavements, the Department for Education specifications restrict the use of such materials for similar applications (e.g., pedestrian paths and paving) in educational facilities. This was affirmed by reviewing these two documents (i.e., DIT South Australia Master Specification RD-PV-S1-Supply of Pavement Materials and Department for Education - Education Facilities Design Standards), freely available online. It should also be noted that two interim standards for recycled timber have been developed by Forest and Wood Products Australia (FWPA) in 2018. The first standard – "Recycled Timber – Visually Stress Graded Recycled Timber for Structural Purposes" – is geared towards the use of recycled timber for structural applications. Alternatively, the second standard – "Recycled Timber – Visually Graded Recycled Decorative Products" – is geared towards the use of recycled timber for decorative applications. However, despite being issued in 2018, both these standards are yet to be reviewed, amended, and developed into formal Australian Standards, suggesting inefficiencies in the standards development process.

4.3.2.6.2 Difficulties in obtaining approvals to use RCMs

The interview findings highlighted that the difficulties in obtaining government approvals for non-typical materials like RCMs deter CPs from using such materials. Herein, IP13-E emphasised that there is less clarity regarding the approval processes in terms of who should be contacted to obtain approval, what information should be provided, and how long it takes to complete the process. This became evident through the following extract from the interview with IP13-E:

> There is a little bit of uncertainty among contractors of how to go about getting approval to use an alternative material…At the moment, there's no instructions given on how to get approval to use a new material, and that's a barrier in itself because there's not, you know, very little certainty over the process and timeframes, who do I need to ask, how long is it going to take, [and] what are they going to ask me to provide.

Consequently, the approval process can become complicated and time-consuming and, as noted by IP13-E and IP22-E, can result in delays to project timelines. IP4-A, IP11-C, IP18-A, and IP27-A also acknowledged that the approval processes have recently become more stringent with fires in high-rise buildings in cities like Melbourne, which has made it more challenging to use alternative materials like RCMs, particularly for commercial applications; "*New requirements around non-combustible materials makes it harder now*," said IP27-A. IP1-E further noted that those who are involved in providing approvals might not be well-versed with RCMs, which can impact whether RCMs are approved for use. In contrast to this general scenario, IP24-A expressed that there is a greater leniency among approval bodies in approving RCMs for heritage-listed buildings to ensure that any modifications preserve the heritage value of these buildings.

4.3.3 Summary of factors limiting the uptake of reprocessed construction materials among construction professionals

Table 4.2 provides a detailed summary of the factors that limit the uptake of RCMs among CPs, identified through the interview findings. These factors were classified against the constructs from ABC Theory (refer to Section 2.8.2.3).

Table 4.2: Summary of factors limiting the uptake of reprocessed construction materials among construction professionals

Factor Classification		Limiting Factor	Explanation
Personal factors	Attitudinal factors	Inherent risk-averseness among CPs in making the virgin-to-reprocessed shift	• Inherent-risk averseness among CPs has limited the shift from virgin materials to RCMs since the responsibility for any project failures associated with using RCMs could come back to them • CPs attempt to minimise any risks of project failure by being limited to tried and tested virgin materials • This is more of a problem when using RCMs for large-scale public or commercial projects where negative connotations associated with project failures are much higher • CPs need someone else to accept any risks associated with using RCMs and would be more open to using these materials in situations where the risks are low (e.g., personal projects)
		Limited concern for environmental credentials when selecting materials	• CPs assign a lower degree of importance to the environmental credentials of materials when making decisions around materiality • This has led to RCMs being relegated to a secondary position behind less environmentally friendly alternatives • Economic considerations and ease of access continue to be the primary drivers of most decisions around materiality, and RCMs are merely seen as "nice to haves" in most cases • Although concerns among CPs in achieving better environmental outcomes are improving, it is slow and not yet mainstream
		Perceptions regarding the inferior quality of RCMs compared to virgin alternatives	• The preconceived idea among CPs that the quality of RCMs is inferior to that of virgin materials limits the uptake of RCMs • Negative quality perceptions can have a stronger influence in limiting the use of RCMs for structural applications where there is a greater responsibility on the part of CPs to ensure structural soundness • These perceptions are reinforced through previous experiences with poor-quality RCMs
		Perceptions regarding the high cost of RCMs compared to virgin alternatives	• With cost being a key decision criterion in material selection, the perception of higher costs of RCMs compared to virgin alternatives discourages CPs from considering RCMs • These perceptions are reinforced through previous experiences with high costs incurred in using RCMs

Factor Classification		Limiting Factor	Explanation
	Personal capabilities	Lack of knowledge and skills required for using RCMs	• The lack of knowledge and skills required for using RCMs limits their uptake among CPs • Mainly a problem among builders due to the lack of training around concepts such as sustainability and material efficiency • An increase in the efforts among CPs to become more knowledgeable about RCMs was observed
		Limited time available to consider RCMs during the material selection process	• CPs are constantly pressured to complete projects within very short timeframes • Therefore, CPs have limited time to consider novel material options like RCMs, that require more research ahead of use • Identified as more of a problem in fast-paced commercial construction projects driven by the urge to capitalise on market opportunities and to recoup the investments made as quickly as possible
	Habits or routines	The tendency among CPs to gravitate towards routinely used materials	• CPs tend to gravitate towards materials that have been repetitively used in the past with successful outcomes • Routine selection of materials is sustained by relationships between CPs and material suppliers • Habits or routines are more established among CPs who have been in the industry for a long time
Contextual factors	Client-related factors	Lack of client interest in using RCMs	• Most clients are not interested in using RCMs, which has limited CPs from considering these materials • Clients are primarily cost-focused, and unless RCMs offer a financial advantage, clients are rarely interested in using such materials • With some RCMs being more costly to use, CPs face the hurdle of convincing clients to see things in a sustainability framework rather than a dollar-and-cents framework • CPs find convincing commercial clients like large developers to use RCMs more challenging due to their money-driven nature
	Organisation-related factors	Lack of support at the organisational level to use RCMs	• CPs are limited by the practices and procedures of their organisations • Therefore, lack of support at the organisational level in enabling the use of RCMs can limit CPs from considering these materials

Factor Classification	Limiting Factor	Explanation
Cost-related factors	Higher cost of RCMs compared to virgin alternatives	• CPs must work within client budgets, and builders specifically have to offer lower costs to remain competitive in the market whilst retaining sufficient margins to ensure business viability • Therefore, RCMs that cost more would be replaced with virgin alternatives • Multiple real-life examples were identified where RCMs had cost more than their virgin alternatives • The development of virgin materials that provide the look and feel of RCMs but at a lower cost has further reduced the popularity of RCMs • Labour-intensiveness of the DW recovery process, the need for specialised technologies, high transportation costs and the lack of economies of scale were identified as possible reasons for the high cost of RCMs
Quality-related factors	Inferior quality of RCMs compared to virgin alternatives	• The quality of RCMs can be inferior compared to virgin alternatives, thus limiting their use • Multiple real-life examples of the inferior quality of RCMs were identified • Quality failures with RCMs can result in problems, such as high levels of wastage, increased material requirements, and the need for rectifications, which can all lead to higher project costs
	Inconsistent quality of RCMs	• Unlike with virgin materials, there could be higher inconsistency with the quality of RCMs, and multiple real-life examples were highlighted to support this claim • The variety of input sources used in manufacturing RCMs and the lack of standards and specifications were recognised as possible reasons for the inconsistent quality
	Lack of certifications or guarantees to ensure the quality of RCMs	• Without the required certifications or guarantees, CPs cannot ascertain whether the quality of RCMs is comparable to that of virgin alternatives or whether the material is suitable for the specific application at hand and, therefore, run the risk of quality failures • Certifications and guarantees are crucial in ensuring compliance with regulations, standards, and codes and in meeting insurance requirements • This also means that additional testing might be needed, which can be costly and time-consuming

Factor Classification		Limiting Factor	Explanation
		Lack of traceability to previous uses	• Lack of traceability to previous uses can raise questions regarding the quality of RCMs (e.g., previous loads held, potential for contaminants being present), thus limiting their use among CPs
	Availability-related factors	Difficulty in sourcing sufficient quantities of RCMs	• Not many suppliers are capable of supplying reasonable quantities of RCMs • Consequently, RCMs will be replaced by virgin alternatives, which are readily available • This is especially a problem in large-scale projects with high material requirements • This necessitates sourcing materials from multiple sources, which can lead to more time, costs, and transportation-related emissions • Limitations with the quantities of DW available for reprocessing were identified as a possible reason for this, and the issue is aggravated by the limited availability of supply sources, especially in regional areas
		Inconsistencies in the supply of RCMs	• Inconsistencies in the supplies of RCMs make it difficult to source these materials on demand • This introduces a higher degree of uncertainty into the material sourcing process, which demotivates CPs from using RCMs • Supply inconsistencies can be related to the limited quantities of DW available for reprocessing
	Regulatory environment-related factors	Limitations with existing standards and specifications related to RCMs	• Existing standards and specifications do not adequately cover RCMs • Without clear standards and specifications, CPs cannot determine the suitability of RCMs for specific applications • Some specifications are outdated and do not have provisions for RCMs • Some standards and specifications explicitly exclude the use of RCMs • Inconsistencies in specifications across jurisdictions limit the widespread use of RCMs
		Difficulties in obtaining approvals to use RCMs	• There is less clarity regarding the approval processes in terms of who should be contacted to obtain approval, what information should be provided, and how long it takes to complete the process, which makes approval processes complicated and time-consuming • Approval processes have become more stringent recently, making it challenging to get RCMs approved

Factor Classification	Limiting Factor	Explanation
		• Those involved in providing approvals might not be well-versed with RCMs, which can impact whether RCMs are approved for use

4.4 Strategies for promoting the uptake of reprocessed construction materials among construction professionals

Promoting pro-environmental behaviours, such as the uptake of RCMs, requires a combination of both informational and structural strategies to address factors limiting behaviour change (refer to Section 2.8.2.4). Herein, the current study identified multiple informational and structural strategies that can be used to promote the uptake of RCMs among CPs, and these are presented in detail through the ensuing sections. Similar to the limiting factors, these strategies were also derived as outcomes from the qualitative survey.

4.4.1 Informational strategies for promoting the uptake of reprocessed construction materials among construction professionals

Informational strategies are primarily aimed at changing the attitudinal factors that limit pro-environmental behaviours. The informational strategies for promoting the uptake of RCMs, identified through the qualitative survey, were classified under five broader sub-categories: (1) information and education, (2) modelling, (3) commitment, (4) feedback, and (5) credibility building. A summary of these strategies is shown in Figure 4.3, with detailed explanations presented in the following sections.

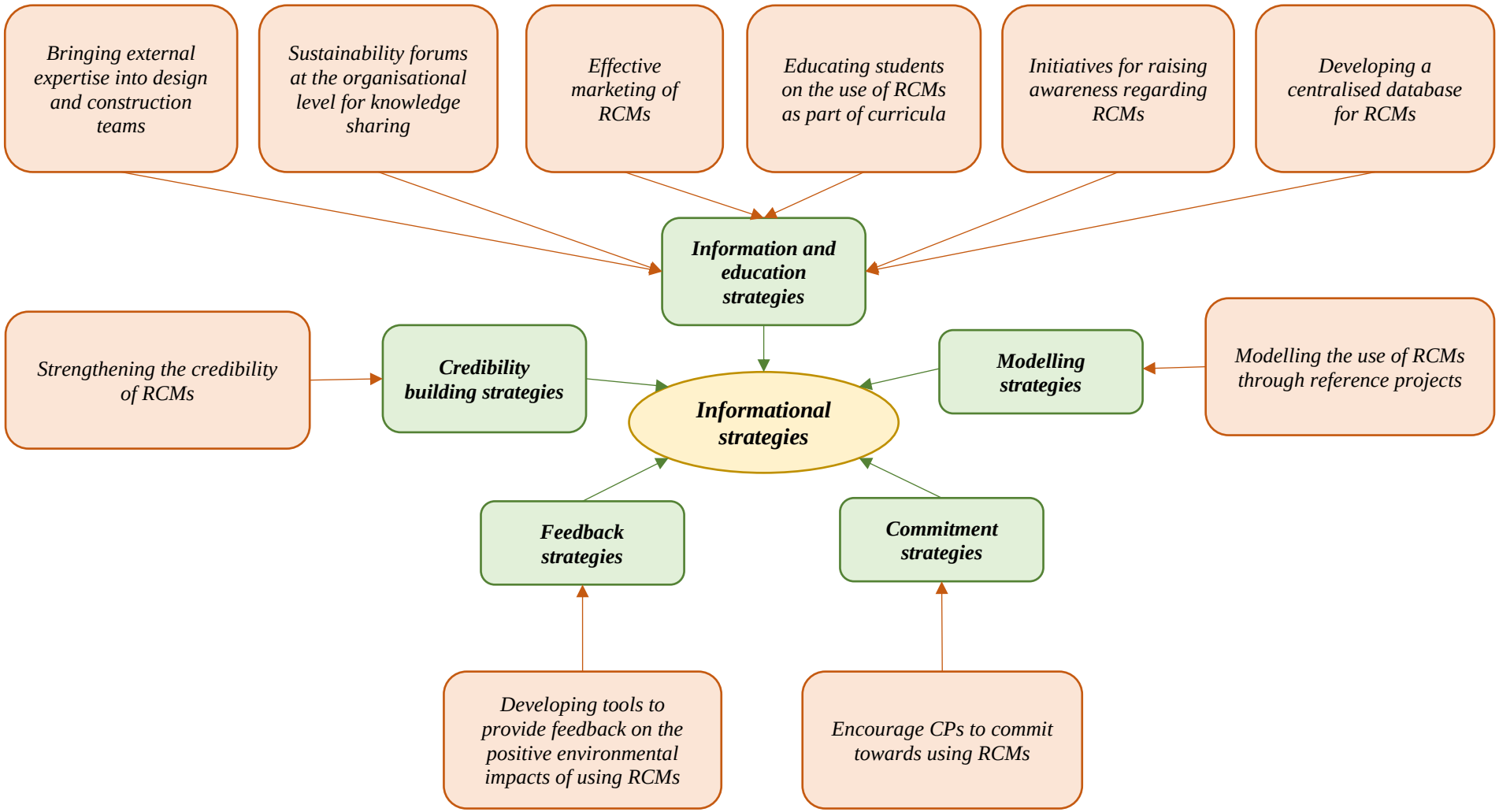


Figure 4.3: A summary of informational strategies for promoting the uptake of reprocessed construction materials among construction professionals

4.4.1.1 Information and education strategies

Information and education strategies aim to increase knowledge among actors about pro-environmental behaviours. The study identified six strategies under this sub-category that can be used to promote the uptake of RCMs among CPs: (1) bringing external expertise into design and construction teams, (2) sustainability forums at the organisational level for knowledge sharing, (3) effective marketing of RCMs, (4) educating students on the use of RCMs as part of curricula, (5) initiatives for raising awareness regarding RCMs, and (6) developing a centralised database for RCMs.

4.4.1.1.1 Bringing external expertise into design and construction teams

Design and construction organisations can obtain the services of external experts, such as ESD Consultants, to encourage and support CPs in using RCMs. IP23-A, having worked as an ESD Consultant, elaborated on the input that these professionals can provide in promoting the use of RCMs as follows:

> ESD Consultants can support engineers, architects, government, and other non-governmental bodies in improving sustainability outcomes, and yeah, a big part of that is undertaking lifecycle analyses, where we're trying to get recycled materials into projects.

Based on their expertise in sustainable construction, these consultants can convince CPs of the significance of having an environmental focus in material selection. They can also advise CPs on the pros and cons of specific RCMs, including their market availability, prior research, potential applications, and limitations. IP1-E, IP4-A, IP5-A, IP6-A and IP17-A all suggested that when a project is geared towards achieving sustainability outcomes, it would be best to engage the services of an expert consultant early in the design process to advise on sustainability-related aspects such as using RCMs. As IP17-A commented:

> When we are going down that track [i.e., a sustainability focus], we would engage someone in that field to advise us, so someone who's in that space all the time, somebody able to help us out.

IP4-A highlighted that engaging such expert consultants can bridge the knowledge gaps among CPs regarding RCMs and also reduce the perceived risks. This is because CPs would then be able to make informed decisions based on professional advice from experts in the field, which would instil greater confidence in their material choices and provide them with a sense of security. Consequently, CPs would be encouraged to be more receptive towards using RCMs.

4.4.1.1.2 Sustainability forums at the organisational level for knowledge sharing

The interviewees underlined that design and construction organisations could establish organisation-wide sustainability forums to share knowledge about sustainability initiatives, including the use of RCMs. Herein, IP10-E highlighted top management support as a crucial driver for establishing such forums. Examples of several such already-established forums were revealed through the interview findings. IP5-A, representing an architectural practice with an established sustainability forum, elaborated on the role that it plays in terms of sharing knowledge about sustainable and green construction practices among CPs within the organisation:

> We have what we would call the national sustainability forum or NSF. They are a group throughout our different studios that come together… we have regular meetings, we educate, we have newsletters, we engage internally within Company X [Original company name mentioned by the interviewee was removed for confidentiality reasons] and are heavily affiliated with other sustainability bodies as well. We focus on providing our design teams with access to ongoing information to design greener buildings and places.

IP5-A affirmed that knowledge sharing on sustainable material options such as RCMs is among the key focus areas of this forum. As highlighted in the above quote, these forums can also serve as a conduit for knowledge sharing between external sustainability bodies and CPs employed within organisations. In a similar vein, IP8-E, representing an engineering consultancy organisation with a sustainability and environmental forum, expanded upon the contribution made by the forum in building awareness regarding sustainable material options, including RCMs, as follows:

> One of the objectives of the sustainability and environmental forum is to provide enough information and enough training and awareness around sustainable design, which includes, you know, the use of recycled materials. So, we are currently working on that to understand the best way to share that knowledge through the business…making sure everyone has that knowledge of the right or wrong applications for some of the materials.

According to the interviewee, these platforms provide the opportunity for CPs to improve their understanding of RCMs and their specific applications. Moreover, IP5-A mentioned that some builders had established sustainability departments within their organisations that promote sustainable construction practices. The interview findings suggest that these forums would facilitate the dissemination of knowledge about RCMs across an organisation, the knowledge that might otherwise stagnate within individual professionals. Furthermore, they can support the integration of external sustainability knowledge into design and construction organisations, which, in turn, increases the awareness of CPs regarding RCMs.

4.4.1.1.3 Effective marketing of RCMs

The findings echoed the importance of RCM suppliers (i.e., waste processors) improving their marketing efforts to provide CPs with the information required for selecting RCMs. Effective marketing is crucial to capture the attention of CPs towards RCMs amidst the abundance of different material options available in the market, which makes it challenging for CPs to be aware of all such material options. Moreover, having readily accessible information is particularly important given the limited time that CPs have upfront to research and select materials for their projects. As expressed by IP17-A,

> It's hard for us to go out looking because there are actually so many materials out there that you go down, you don't know what's what. So, it takes a lot of time to find the information you want and to educate yourself, and then to convince the client as well.

The findings suggested that the marketing efforts should concentrate on informing CPs about the RCMs available, their quantities and associated costs. Similarly, suppliers should provide information on testing results and certifications to determine the suitability of RCMs for specific applications and offer further guidance on the appropriate uses of these materials. IP9-E mentioned that marketing communications could also provide details on previous successful applications of RCMs, thereby instilling confidence among CPs regarding the performance of these materials. Moreover, IP10-E and IP17-A emphasised that the environmental benefits of using RCMs, such as the potential savings on carbon footprint and embodied emissions, conservation of virgin materials, and the diversion of DW away from landfills, should be highlighted as a part of marketing efforts to make these materials more appealing to environmentally conscious users and projects.

Commenting on the marketing methods, the interviewees asserted that a combination of physical and electronic marketing methods could be used to promote RCMs among CPs. This would help to provide detailed insights about RCMs where necessary while simultaneously capturing the attention of a broader audience. According to IP16-C and IP21-A, easy access to material information over electronic platforms such as websites avoids the need for CPs to contact multiple suppliers or physically visit supplier facilities, thereby cutting down both the time and costs involved in material sourcing.

The interviewees affirmed that improved marketing of RCMs removes friction from the process of material sourcing and is crucial for enhancing awareness regarding these materials and showcasing them as viable alternatives for virgin materials, thus fuelling the virgin-to-reprocessed shift. As expressed by IP26-C:

> By getting more information out there to industry professionals, we will be able to create a greater emphasis for them to think outside the box and use reprocessed materials within projects.

Interestingly, the findings revealed that the marketing efforts for RCAs had advanced further compared to other RCMs and, as per IP10-E, has thus enhanced the popularity of RCAs among CPs.

4.4.1.1.4 Educating students on the use of RCMs as part of curricula

The study findings underscored that educational institutes such as universities and technical colleges must educate students coming through these institutes on the use of RCMs as a part of their curricula, thus laying the foundation for them to expand their knowledge later through practice. According to the interviewees, such educational programs must focus on two areas – one is to highlight the importance of considering environmental impacts and alternative material options such as RCMs during material selection, and the other is to educate students specifically about RCMs and how they can be incorporated into construction works.

Firstly, IP3-A, IP12-C, IP19-A, and IP27-A noted that students could be taught about broader concepts related to sustainable construction, such as circular economy, closing waste loops, and minimising carbon footprint and embodied emissions. Knowledge of these concepts would encourage students to consider the environmental impacts of their material choices, and invariably RCMs, since using RCMs aligns closely with the principles outlined under such concepts. For example, because RCMs are produced with DW, which are otherwise destined for landfills, these materials will help close waste loops and achieve circularity in built environments. Similarly, since the energy expended in producing RCMs is generally less than that used for producing virgin materials, using RCMs can be considered a potential avenue for minimising the carbon footprint and embodied emissions associated with construction projects.

Secondly, the curricula need to specifically focus on RCMs, which can include educating students on the different types of RCMs available in the market, their potential applications, how they can be incorporated into new construction works, and any specificities related to working with these materials that differentiate it from working with virgin alternatives. IP3-A expressed the need to "*Educate designers around what reprocessed materials are available, where to find information and technical data.*" Further, IP13-E elaborated on the potential differences encountered when using RCMs rather than virgin materials through the example of concrete mixes with recycled aggregate

replacement. The interviewee affirmed that such differences must be captured as part of training and capacity building for CPs:

> There are some contractors who are unfamiliar with those mixes, with, you know, high replacement levels, so there's more training or capacity building needed there because those mixes, you know, perform a bit differently (IP13-E).

Moreover, the findings revealed that certain specialised skills might have to be developed for working with RCMs and that such skills should ideally be incorporated into curriculums. The following extract from the interview with IP12-C elaborated on this in detail:

> A skill that I learned of an old-school builder, which is how to go into one of those yards and actually dig through and find stuff that's good, and the stuff that probably should have been cut off into firewood, and how to do that quickly. Because we have apprentices that I've showed second-hand stuff, and I'm like, what do you think of this? Well, it looks fine. I'm like, well, you know, that bits no good, that bits been eaten by termites at some point in its life…So, but that's a learnt skill, you know…combining that with education and including in curriculums for say Cert III [Certificate III] in carpentry…so education is the key.

IP3-A, IP8-E, IP11-C, and IP12-C asserted that builders exhibit a relatively lower degree of awareness regarding RCM-related concepts when compared to professionals such as architects and engineers despite being the ones who are responsible for physically constructing the project on-site. The interviewees attributed this to a lack of training opportunities for builders. As stated by IP12-C:

> There's not enough training for builders…So, it means that for your average sort of builder, who's followed, say, the carpentry road to becoming a builder or even guys who have done construction management, they are not necessarily all that exposed to the real world of sustainability until they actually decide they want to seek it out for themselves.

Therefore, it was recommended that the curricula for builders be updated to accommodate these concepts to ensure they are equipped with the knowledge to use RCMs effectively.

In summary, findings echoed the importance of educating those who aspire to become CPs on using RCMs since they represent the next generation of professionals with the baton to change the industry. If CPs are not educated on these areas during the early stages of their career, it is less likely for them to get interested and learn about these concepts later since the use of RCMs is still at an infant stage, which limits the opportunities for learning through practice.

4.4.1.1.5 Initiatives for raising awareness regarding RCMs

The findings placed emphasis on initiatives to raise awareness among CPs regarding RCMs and the importance of considering such alternative environmental-friendly material options. Such initiatives can be undertaken both at the governmental and non-governmental levels through government departments, local government bodies, sustainability organisations or professional institutes.

At the governmental level, these initiatives can be undertaken in different forms, such as forums for knowledge sharing (e.g., conferences, talks/presentations), developing guidance materials, and providing specialist advice. According to the interviewees, knowledge-sharing forums help to build a nexus between RCM suppliers and CPs by providing a platform for suppliers to showcase their materials and for CPs to learn about them firsthand. Similarly, government organisations can also be involved in developing guidance materials to assist CPs in using RCMs. IP2-E, IP9-E, and IP13-E highlighted that some government organisations, including VicRoads (Department of Transport and Planning from 1st January 2023) and DIT South Australia, have already advanced in this area by developing technical notes and performance comparisons between virgin and RCMs used for road infrastructure projects. IP3-A, IP17-A, and IP22-E also noted that local councils could provide specialist advice on environmentally responsible material selection through sustainability officers typically employed by most councils.

The interviewees noted that similar initiatives for building awareness could also be undertaken at the non-governmental level. Herein, special attention was drawn towards the role of professional institutes (e.g., Engineers Australia, Australian Institute of Architects, Master Builders Australia, Australian Institute of Building) in organising continuing professional development (CPD) programs to educate CPs about RCMs and equipping them with specialised skills that may be required when using such materials. The use of CPD sessions for increasing awareness was recognised as an apt measure for providing a more expansive reach since CPs are obligated to complete a specific number of CPD hours annually to retain their membership. As expressed by IP17-A,

> We, as professionals, need to undergo continuing professional development…So, every year, we have to do a certain amount of hours of learning…that's one way in which the institute [i.e., professional institute], by putting on these events, can educate us.

IP14-C added that professional institutes could also organise forums to connect RCM suppliers and CPs to facilitate knowledge sharing. The interviewees further highlighted the

role that sustainability organisations such as the GBCA and the Infrastructure Sustainability Council of Australia (ISCA) could play in organising industry events aimed at knowledge sharing on RCMs. These organisations could also develop guidance materials to assist CPs in utilising RCMs effectively and support suppliers in promoting RCMs among their members.

Awareness created through these governmental and non-governmental initiatives will help overcome the negative connotations around RCMs, which were found to be significant contributors to the low uptake of such materials. Furthermore, these initiatives can serve to address any knowledge and skill gaps among CPs regarding these materials.

4.4.1.1.6 Developing a centralised database for RCMs

The current system for searching and sourcing RCMs is based on contacting individual suppliers to check material availability, which makes it difficult and time-consuming to access information related to these materials. Therefore, the interviewees recommended the development of a centralised database dedicated to RCMs, which provides easy access to information on reprocessed material options offered by different suppliers in the market. The significance of having such a centralised database was highlighted by IP24-A as follows:

> Often, I will talk to some of the trades if I need a particular thing, and they will direct to me, you know, in terms of where they believe somebody might have something. It's kind of a word-of-mouth thing. There's not like a directory of who has what in any particular time. So, in that sense, I suppose it's not very organised (…). I think something more organised in terms of trying to identify these materials (…), that would be very useful in terms of trying to track things down.

The database could be developed and maintained by a governmental body (e.g., an Environmental Protection Authority) or a non-governmental body such as a sustainability organisation or a professional institute (e.g., Green Building Council of Australia (GBCA), ISCA, Planet Ark, Australian Institute of Architects, Master Builders Australia). According to the interviewees, the database should ideally be in an electronic format (i.e., website or mobile application), user-friendly and easy to navigate, and updated regularly to facilitate easy access to up-to-date information regarding RCMs.

According to IP3-A, IP7-E, IP16-C, and IP24-A, the database should contain information about the RCMs available, their suppliers and costs, while IP19-A and IP24-A added that information on supplier locations should also be included. The latter recommendation was based on the fact that long-distance transportation would result in high transportation costs

and increased transportation-related carbon emissions that could potentially negate the environmental benefits of using RCMs. Further, IP3-A noted that material gradings and performance levels could be added to the database, while IP13-E proposed that testing results and environmental data (e.g., carbon footprint, lifecycle impacts) can also be incorporated. A basic outline of the expectations of the database is shown in Figure 4.4.

Some suppliers were seen to be using established e-commerce platforms like Gumtree [an online platform for classified advertisements and community interactions] to market RCMs. However, according to IP12-C, such platforms are not dedicated to RCMs and are, therefore, unsuitable for CPs trying to source reliable supplies of RCMs. Nevertheless, as pointed out by the interviewees, an interesting development in this area is the 'ISupply' database developed by ISCA, which contains information about suppliers of more sustainable materials that can be used for ISCA-rated infrastructure projects. The interviewees suggested that this database can be expanded to cover all RCMs without being limited to materials used for infrastructure projects and to provide more information on the available quantities and costs of the materials, which are currently not captured.

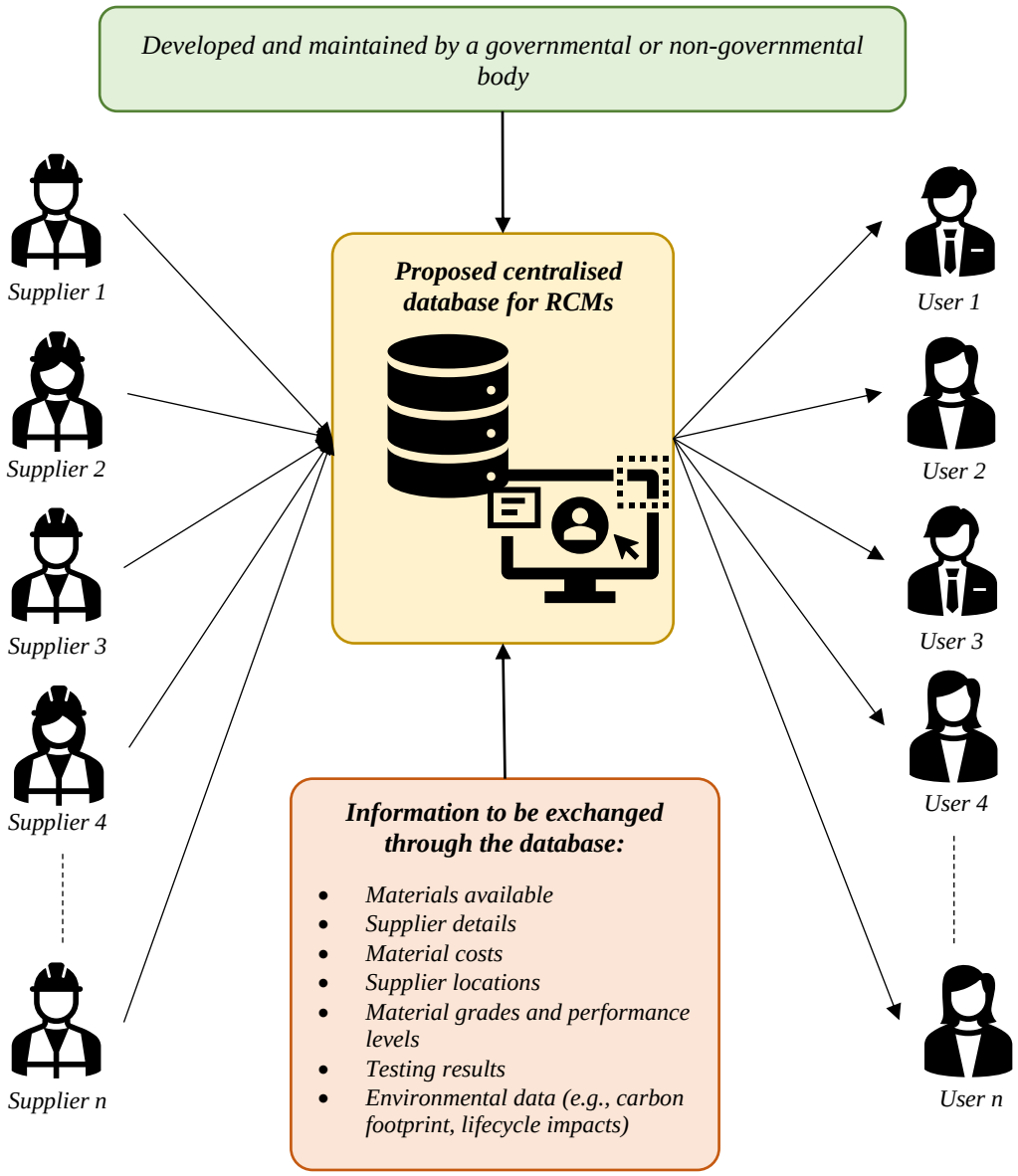


Figure 4.4: Basic outline of the expectations of the proposed database

4.4.1.2 Modelling strategies

Modelling is an informational strategy that involves providing examples of recommended behaviours. Herein, modelling the use of RCMs through reference projects was identified as a potential strategy for promoting the uptake of RCMs among CPs.

4.4.1.2.1 Modelling the use of RCMs through reference projects

Modelling the use of RCMs through reference projects was highlighted by the interviewees as a potentially suitable strategy for driving the uptake of RCMs among CPs. These reference projects would demonstrate how RCMs can be used in practical construction applications and their benefits, thus increasing the knowledge base around these materials and encouraging CPs to follow suit and adopt similar methodologies. As expressed by IP6-

A, "*It's just about getting the information out there and demonstrating good case studies so that people can see how they can be used and how successful that can be*." Good case studies can boost the confidence of CPs in transitioning to RCMs. Herein, IP25-C mentioned that as more reference projects are conducted using various RCMs, and that information is shared throughout the industry, CPs would be more open and comfortable choosing RCMs over virgin alternatives.

The interviewees identified this as a strategy to be implemented primarily by the government since they undertake a significant number of construction projects that can serve as exemplar projects for demonstrating the potential of RCMs. As IP18-A stated:

> Government projects, they should demonstrate this, so like all school buildings, you know; there's so much infrastructure the government builds, [and] that's a really great opportunity to support the development of that whole market.

This use of RCMs in government projects would then inspire CPs involved in private sector projects to emulate such practices and follow suit. Commenting on this, IP11-C mentioned:

> The government's got to push it themselves and see if the market takes it, you know, then, the rest of the market's going to have to catch up…they are going to have to start improving.

Interestingly, some government projects, especially in the infrastructure sector, were found to be already using these materials. A prominent example is Victoria's Big Build, aimed at delivering more than a hundred major road and rail projects across the state. These projects target replacing virgin materials with reprocessed alternatives as a priority consideration (Victoria's Big Build 2022). The interviewees expressed that learnings from such projects on using RCMs should be shared across the industry for other projects to follow. However, IP13-E mentioned that there are currently no mechanisms to capture information about the use of RCMs in these projects, rendering such information unavailable for reference. Therefore, the interviewee recommended developing a reporting tool that requires builders to enter information on types and volumes of RCMs used in different projects and applications. This information could then serve as a knowledge repository for future projects to draw from.

Several interviewees noted that in addition to the government, sustainability organisations such as GBCA and ISCA could also play a role here by disseminating information about successful sustainability-rated projects that have used RCMs, which can be used as reference projects for CPs to emulate.

4.4.1.3 Commitment strategies

Commitment strategies involve requesting individuals to commit towards undertaking certain behaviours. Herein, encouraging CPs to commit towards using RCMs was recognised as a potential strategy for promoting the uptake of RCMs.

4.4.1.3.1 Encouraging CPs to commit towards using RCMs

The interview findings highlighted that professional institutes could encourage their members to make written public commitments towards increasing the use of RCMs. IP8-E and IP10-E noted that such commitments would increase the likelihood of CPs following through with the commitment and taking action to increase their use of RCMs. When the commitment is made public, it creates social pressure to follow through with the commitment, even if faced with challenges or obstacles that deter its fulfilment. IP8-E and IP10-E underlined the Australian Engineers Declaration on Climate and Bio-Diversity Emergency as an example of a commitment strategy that encourages the adoption of sustainable practices among Australian built environment engineers. The declaration highlights the significance of engineers considering avenues to mitigate the risks of climate change and biodiversity loss as a priority concern in their practices. By becoming a signatory to this declaration, engineers commit towards mitigating climate change and biodiversity loss through their practice. This commitment is made publicly, and anyone can see who the signatories are. Therefore, any violation of this commitment is open for public scrutiny, thus creating social pressure on the signatories to follow through with their commitment. Accordingly, encouraging CPs to make such commitments can result in an increase in the uptake of RCMs.

4.4.1.4 Feedback strategies

Feedback involves providing individuals with insights about their performance and outcomes of specific tasks and influences behaviour by helping individuals understand the relationship between their performance of a specific task and achieving a specific outcome. Developing tools to provide feedback on the positive environmental impacts of using RCMs was identified here as a potential strategy for promoting the uptake of RCMs among CPs.

4.4.1.4.1 Developing tools to provide feedback on the positive environmental impacts of using RCMs

The interviewees highlighted that governmental or non-governmental bodies could develop tools to provide CPs with feedback on the positive environmental impacts of using RCMs.

These tools can be developed to calculate environmental impact indicators such as the carbon emissions associated with using different RCMs and their virgin alternatives. This would enable CPs to see the environmental benefits of using RCMs over virgin materials, thereby prompting them to consider RCMs during material selection. IP8-E elaborated on the benefit of having such tools as follows:

> …providing carbon calculators for, you know, some of the projects, so you could go a sustainable route and save this many tonnes of CO_2, or you can go with the traditional route, you know, everything virgin and this is the dent in the ozone you're going to create essentially. So, it literally comes down to those sorts of numbers so we can make the right decisions now and use it to our advantage.

This extract emphasised that having numeric data can better inform the material choices made by CPs, a fact that was also supported by IP27-A, who mentioned that people's mindsets could be changed when provided with quantifiable data. Feedback from these tools can help CPs conveniently monitor the environmental impacts of their material choices and alter them accordingly. Interestingly, IP13-E mentioned that ISCA, as a part of their sustainability rating scheme, has a materials calculator with lifecycle data for a range of traditional materials to help CPs calculate carbon emissions, lifecycle impacts and environmental points of the different materials that go into an infrastructure project. Such tools can be the starting point for developing tools that can also calculate the environmental impacts of using RCMs.

4.4.1.5 Credibility building strategies

Credibility building is where information is provided through trusted sources to increase the likelihood of the information being acted upon by the target audience. Herein, strengthening the credibility of RCMs was identified as a potential strategy for promoting the uptake of RCMs among CPs.

4.4.1.5.1 Strengthening the credibility of RCMs

The confidence of CPs in embracing the use of RCMs can be improved through the provision of reliable information from trusted sources. The interviewees emphasised the significance of the endorsement of RCMs from trusted governmental and non-governmental bodies since this would enhance the credibility of RCMs in the minds of CPs. Echoing this idea, IP27-A expressed, "*I've witnessed first-hand that when presented with reliable data, we can change people's mindsets about recycled materials."* Multiple interviewees affirmed that research is a pivotal aspect in building such credibility and expressed that governmental and non-governmental bodies as well as educational

institutes, can all play an active role in this regard. Such research on RCMs can provide CPs with credible insights into the benefits/positives of RCMs, which would help address the negative connotations around these materials and bolster market confidence. Notably, the absence of solid research on RCMs appears to instil hesitancy among CPs to adopt these materials, as mentioned by IP1-E; "*If you don't have a research sort of background, you just don't necessarily take on board the benefits.*" Interestingly, the interviewees noted that some governmental and non-governmental initiatives in several states already drive research on alternative material solutions, including RCMs, primarily in the infrastructure sector. One example is the National Asset Centre of Excellence (NACOE) in Queensland, which is an initiative of the Queensland Department of Transport and Main Roads and the Australian Road Research Board for leading road asset research. Sustainability is among the key discipline areas of this initiative, and it has a strong focus on the development of environmentally friendly material solutions for road infrastructure. Another example is the Western Australian Road Research Innovation Program (WARRIP) in Western Australia, which also targets the development of alternative environmentally friendly material options for road infrastructure. The findings suggested that such initiatives can be expanded to support research on a broader range of materials covering both the building and infrastructure sectors, thus further strengthening the credibility of RCMs in the minds of CPs.

4.4.2 Structural strategies for promoting the uptake of reprocessed construction materials among construction professionals

Structural strategies are aimed at addressing the contextual factors and habits or routines that limit pro-environmental behaviours. The structural strategies for promoting the uptake of RCMs, identified through the qualitative survey, were classified under two broader sub-categories: (1) infrastructural strategies and (2) legislative and policy strategies. A summary of these strategies is shown in Figure 4.5, with detailed explanations presented in the following sections.

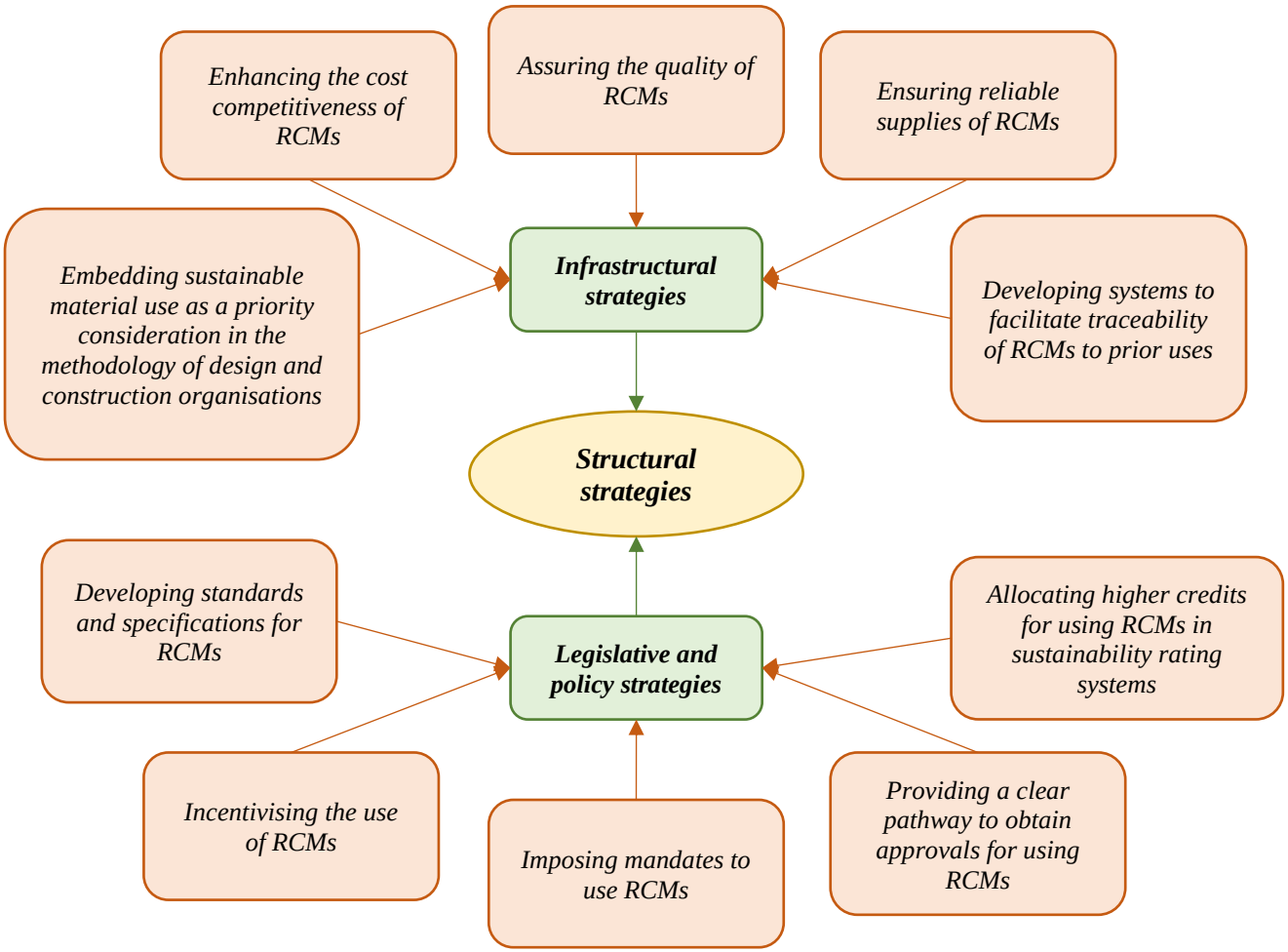


Figure 4.5: Summary of structural strategies for promoting the uptake of reprocessed construction materials among construction professionals

4.4.2.1 Infrastructural strategies

Infrastructural strategies involve modifying physical, technical, and organisational systems to change the availability and viability of different pro-environmental behavioural alternatives. The findings identified five strategies under this sub-category that can be used to promote the uptake of RCMs among CPs: (1) embedding sustainable material use as a priority consideration in the methodology of design and construction organisations, (2) enhancing the cost-competitiveness of RCMs, (3) assuring the quality of RCMs, (4) ensuring reliable supplies of RCMs, and (5) developing systems to facilitate traceability of RCMs to prior uses.

4.4.2.1.1 Embedding sustainable material use as a priority consideration in the methodology of design and construction organisations

Design and construction organisations can facilitate CPs to consider RCMs during material selection by embedding sustainable material use as a priority consideration in the organisation's methodology. According to IP20-A, such an approach will encourage CPs to consider sustainable material options like RCMs at the outset of a project and discuss with clients the viability of proceeding with reprocessed options. Alluding to this, IP18-A mentioned that organisational support for sustainability initiatives could empower CPs to have a conversation about using RCMs with clients during the briefing stages, which ultimately sets the tone for decisions that follow. Interestingly, IP25-C expressed that as the construction industry moves towards being less carbon-intensive, initiatives such as using RCMs would be more readily supported and adopted by most design and construction organisations in the future.

4.4.2.1.2 Enhancing the cost competitiveness of RCMs

Construction projects operate under tight budgets, and many decisions around materiality can ultimately come down to cost. Therefore, with most RCMs being sold at higher price points when compared to their virgin counterparts, the interviewees emphasised that waste processors must focus their attention on enhancing the cost competitiveness of RCMs. The findings acknowledged that it could be challenging to use RCMs when there is a cost premium associated with them and that any additional spending on RCMs, when a virgin alternative can offer the same functionality at a lower cost, would not be considered favourably by the industry. As expressed by IP10-E, "*This* [use of RCMs] *comes down to price as well, you know; you need to have a good comparison of price between reprocessed and virgin materials*."

If the costs of RCMs are comparable to virgin alternatives and using these materials made more economic sense, the interviewees acknowledged that there would be a higher level of acceptance for RCMs. Herein, IP21-A commented,

> If it made more economic sense, then yeah, we will use a whole lot more recycled materials – people will pay a bit more to do the right thing, but not a lot more, the only way it's going to happen is if it becomes more economically viable.

In supporting this assertion, IP24-A mentioned that more people would naturally shift towards RCMs if they became more economical to use than virgin materials. This is evidenced by the increased use of RCAs, whose costs are comparable to virgin quarried aggregates. As noted by IP23-A, "*We are seeing more and more recycled aggregates being used; the price is coming down on that, so it's becoming more prevalent."*

The findings emphasised that waste processors should look at avenues for improving the efficiency of the waste recovery processes and eliminate any avoidable costs, which can make RCMs more cost-competitive. As affirmed by IP16-C, "*When there's a process for actually getting that cost down and making it comparable with a new product, that's when they'll start using those products*". Similarly, IP28-C highlighted that the waste recovery industry should look for alternative, more convenient, less costly, and efficient recovery methods.

4.4.2.1.3 Assuring the quality of RCMs

Quality concerns were commonly recognised as a factor that limits the uptake of RCMs. IP2-E mentioned that unless the quality of RCMs is on par with virgin materials, it does not make much sense for CPs to nominate such materials since the responsibility for any quality failures can ultimately come back to them. Therefore, the interviewees expressed that the waste recovery industry must be reorganised as a specialised industry with better quality control procedures to ensure that RCMs have superior and consistent quality. "*Care should be taken throughout the recovery process to ensure the materials are preserved well; the quality assurance processes implemented are critical*," said IP26-C. IP31-C alluded to this notion and mentioned that the DW recovery processes must be well-organised and sophisticated to provide a quality output. Moreover, the importance of rigorous testing regimes, product certification, and performance guarantees was reiterated to ensure that RCMs are of acceptable quality and meet industry standards.

Elaborating on testing requirements, IP9-E, IP10-E, IP11-C, IP13-E, and IP15-C commented that waste processors must undertake appropriate testing to ascertain the

quality of RCMs and ensure that the materials perform adequately, are of consistent quality, are free from contaminants, and comply with the requirements of the industry standards. As argued by IP11-C, without appropriate testing confirming the quality of RCMs, CPs cannot be reasonably expected to move away from tried and tested virgin materials and accept RCMs. IP22-E further contended that by subjecting RCMs to rigorous testing regimes, waste processors could drive relevant government authorities to include these materials in industry specifications, thus promoting their widespread acceptance across the industry. As elaborated by IP22-E,

> When you want to go outside those specifications, say it has got more recycled materials than what your specification allows, but they've done all this testing to demonstrate it's just as good, then they'll [parties developing industry specifications] get that into the specification, then it becomes, you know, 'everyone can use it' type stuff. So, that's generally how that sort of evolves…it's a gradual process of checks and balances before it sort of starts to then get into the mainstream specifications for the works.

While undertaking appropriate testing, the interviewees noted that waste processors could opt for third-party quality certifications, which would help them improve the quality of their outputs. Such certifications would also provide CPs with more certainty over the quality and performance of RCMs. The market confidence created through these certifications will increase the likelihood of RCMs being adopted. As expressed by IP15-C:

> Certification… I think that's where you get the peace of mind, and those materials are more likely to be taken up generally within the industry sooner because they've got… people have got some confidence that it does meet required standards and it's not going to be an issue or a liability on them down the track.

IP11-C and IP28-C pointed out that as construction projects increasingly demand certified materials, RCM suppliers would have to focus more on obtaining certifications for their materials. IP19-A went on to mention that certification requirements are more of a concern when using RCMs for structural applications. As expressed by the interviewee,

> When you think about reusing wood, for example, for a structural aspect, that's where it starts to be complicated. If the industry is able to certify reprocessed wood for structural construction, and I'm speaking about wood, but it's the case for different structural elements, it becomes much easier.

Study findings suggest that certifications can also have practical benefits for insurance purposes and for obtaining construction approvals. IP5-A stated that possessing appropriate certifications can streamline insurance verification processes, while IP6-A observed that certified materials are more likely to be approved for use during building

assessments. The findings indicated that waste processors could consider quality certification schemes like ISO 9001 that focus on ensuring process quality, ultimately improving output quality. IP3-A added that waste processors could also offer guarantees with RCMs, which can further improve market confidence regarding the quality of these materials; "*If it is organised as a specialised industry and offered performance guarantees and standard guarantees…that would definitely be a positive*," said IP3-A.

Interestingly, despite specific issues with the quality of RCAs being noted in the past, multiple interviewees affirmed that the quality of these materials has improved and that quality failures have become rare over time. Even the interviewees who noted quality issues with RCAs like IP1-E, IP2-E, and IP22-E affirmed that the quality of these materials has witnessed a notable improvement and that suppliers are working proactively towards improving their quality. As stated by IP22-E:

> The main problem we've had with it [RCAs] is contaminants getting caught up in it, but that has improved a lot since then, so the industry got aware of it, and they sort of are working out for it.

4.4.2.1.4 Ensuring reliable supplies of RCMs

The study findings underscored the importance of waste processors focusing on ensuring supply reliability so that sufficient quantities of RCMs could be sourced consistently and in a timely manner. According to the interviewees, ensuring supply reliability requires a dual focus on two key aspects; (1) ensuring that sufficient quantities of RCMs are available and (2) ensuring that materials can be sourced consistently.

Firstly, commenting on the need to ensure the availability of sufficient quantities, IP1-E, IP19-A, and IP21-A expressed that waste processors must maintain reasonably large stocks of RCMs to enable CPs to source these materials without experiencing stockouts. As stated by IP19-A,

> It goes back to the quantities when it's about specifying them, so we don't need suppliers of small bits and pieces; we need to make sure that those materials, even if they are reprocessed, are available in a quantity reasonable.

The interviewee further noted that such large stocks of RCMs would enable CPs to source these materials from a single source rather than collecting small quantities from multiple sources, which can be costly, time-consuming, and result in high transportation-related emissions.

Secondly, concerning supply consistency, IP4-A, IP6-A, IP11-C, and IP19-A commented that waste processors must maintain a steady stream of materials, enabling CPs to source

RCMs as and when required. Consistent supply is critical in current construction environments driven heavily by tight project timelines. As expressed by IP17-A, unless the supplies of RCMs are as reliable as those of virgin materials, it would be difficult for them to compete against virgin alternatives. Therefore, it is imperative for waste processors to structure their processes to supply sufficient quantities of RCMs consistently as and when demanded by the market. However, the interviewees were unable to comment on how waste processors could ensure reliability in the supply of RCMs. Interestingly, multiple interviewees noted that the supplies of RCAs have become more reliable over time compared to other RCMs, rendering them a viable alternative that could be considered alongside virgin aggregates.

4.4.2.1.5 Developing systems to facilitate traceability of RCMs to prior uses

The findings reckoned that the lack of traceability to previous uses could raise questions regarding the quality of RCMs, which limits their use. Therefore, waste processors must develop systems to track RCMs to their previous uses to overcome this issue. According to IP11-C, tracking material origins can inform future uses of RCMs and mitigate the risk of quality failures associated with using materials from unknown origins. As expressed by the interviewee,

> Chain of custody, if that can be tracked, then you'd get a better understanding of where it should be used in future. But if you don't know the chain of custody, if it comes from a recycler [waste processor], and he doesn't know where it's coming from, then there's absolutely risk in that regard.

Traceability to prior uses is crucial for materials such as reprocessed bricks and timber, whose original use directly impacts the secondary use. For instance, bricks and timber sections originally used for internal applications might not be suitable for external uses due to the inability to withstand extreme weather conditions.

IP1-E, IP11-C, and IP23-A further noted that traceability is also crucial when opting for sustainability ratings such as Green Star and LEED, which demand a good audit trail of materials. As expressed by IP23-A, "*If we are going for certifications like Green Star or LEED, they require material tracking… saying where we got what we wanted*." Establishing tracking systems can, therefore, increase the chances of RCMs being adopted for sustainability-rated projects, which is where these materials are more likely to be considered. IP18-A identified Building Information Modelling (BIM), digital twins, and Radio Frequency Identification (RFID) as enabling technologies for material tracking.

However, the interviewee noted that the industry is still a fair way away from realising the full potential of such technologies.

4.4.2.2 Legislative and policy strategies

Legislative and policy strategies involve the use of legal regulations and policies (e.g., pricing policies) to promote pro-environmental behaviours. The findings identified five legislative and policy-related strategies that can be used to promote the uptake of RCMs among CPs: (1) developing standards and specifications for RCMs, (2) incentivising the use of RCMs, (2) imposing mandates to use RCMs, (4) providing a clear pathway to obtain approvals for using RCMs, and (5) allocating higher credits for using RCMs in sustainability rating systems.

4.4.2.2.1 Developing standards and specifications for RCMs

According to the interviewees, RCMs that can and cannot be used for construction projects are heavily determined by industry standards and specifications; "*It's up to the standards and specifications to really indicate what's allowed in the reprocessed area*," said IP1-E. Therefore, the government must focus on developing standards and specifications targeting RCMs to facilitate their use. Where reprocessed alternatives for virgin materials exist, the standards and specifications must be adjusted to accommodate both virgin and reprocessed options. As expressed by IP28-C:

> The best thing the government can do is to make sure that the standards and specifications clearly allow for the use of reprocessed materials in every case where there is a virgin counterpart…that will be the one thing that changes the uptake of reprocessed materials in construction.

The study findings highlighted the significance of standards and specifications being tailored for RCMs since there are specificities associated with using RCMs that might not apply to using virgin alternatives. For example, IP1-E expressed that the specifications for RCAs should have testing requirements around asbestos contamination, which might not be highly relevant when using virgin quarried aggregates. IP2-E and IP13-E added that the standards and specifications for RCMs should be more relaxed and offer a wider window of performance compared to virgin materials since RCMs might not be able to meet the same performance levels as virgin alternatives. For instance, IP13-E noted that the specifications for RCAs used as road bases could include some allowance for foreign materials such as bricks and tiles, which would not significantly affect the material's performance when used for the said application.

Elaborating on how the specifications must be developed, IP1-E commented that the specifications should be performance-based rather than recipe/prescriptive-based[1], thus allowing a more comprehensive range of RCMs to be considered for achieving a specified performance outcome. As stated by the interviewee,

> So, if you have a recipe specification, the recipe specification doesn't allow for many recycled materials; so, you have to have a performance parameter instead of a recipe to be able to see what they are…so that you try actual tests and determine its properties to see whether it's suitable or not.

The interviewee also reckoned that standards and specifications should be developed ideally at the national level to ensure their applicability across multiple jurisdictions. Such an approach requires the collective efforts of authorities responsible for developing standards and specifications in each state or territory. However, IP1-E and IP13-E noted that these bodies are currently following individualised approaches for developing standards and specifications, which can result in differences in the use of RCMs across different jurisdictions. Interestingly, IP13-E highlighted that Austroads is attempting to develop a nationally consistent set of model specifications for the use of RCMs in road projects, which, when completed, will provide a uniform approach for using such materials in road projects while simultaneously facilitating cross-border trade of these materials.

Study findings further emphasised that standards and specifications would not only encourage CPs to select RCMs but also drive waste processors to process these materials to meet the requirements outlined in these documents. Consequently, CPs can be less apprehensive about shortfalls or inconsistencies with the quality of RCMs. This was pointed out by IP9-E based on an example of using RCMs for road pavements:

> Making sure the standards are there for suppliers of pavement materials…they know what the specification is, and when we take that, when that material is obtained, it's to the required standard, so no contaminants or the like.

[1] Difference between prescriptive and performance-based specifications (Taken from: Lam, PT, Kumaraswamy, MM & Ng, TS 2003, A comparative study of user perceptions on prescriptive specifications versus performance-based specifications): Prescriptive specifications are used "*when the specifier wishes to dictate the required properties of a product, material, or equipment, as well as the workmanship required for its proper installation (e.g., a concrete mix specified to have four-part coarse aggregates, two-part fine aggregates and one-part cement with 0.5 water-cement ratio is prescriptive)* (p.22)." Alternatively, in performance-based specifications, "*the specifier states the required results (say concrete of 30MPa compressive strength at 28 days), the criteria by which performance will be judged and the methods of verification (say by trial mixes and compression tests). The contractor is free to choose materials, proportions, methods, and systems to produce the required result* (p.22)."

In parallel with developing standards and specifications, IP1-E, IP13-E, and IP26-C emphasised that these documents must be reviewed and updated periodically as new RCMs enter the market.

According to the interviewees, infrastructure specifications have become more attuned to RCMs over the last few years, thus notably reducing the barriers towards using these materials in infrastructure projects. The proliferation of infrastructure specifications related to RCMs is further affirmed through the Austroads Guide to Pavement Technology Part 4E: Recycled Materials released in 2022. Table 4.3 below, adapted from the guide, provides a state-based summary of infrastructure specifications that have considered RCAs as road pavement materials. This shows that most states have taken an interest in using such RCAs in infrastructure-related applications.

Table 4.3: State-based specifications for recycled concrete aggregates in infrastructure applications (Adapted from Clark et al. (2022))

The government agency responsible (State)	Specifications and guides used at the state-level
Department of Transport and Main Roads (Queensland)	• MRTS05 Unbound Pavements • MRTS08 Plant Mixed Heavily Bound Pavements • MRTS09 Plant Mixed Foamed Bitumen Stabilised Pavements • MRTS10 Plant Mixed Lightly Bound Pavements • Pavement Design Supplement to 'Part 2: Pavement Structural Design' of the Austroads Guide to Pavement Technology
Transport for New South Wales (New South Wales)	• QA Specification 3051 Granular Pavement Base and Subbase Materials • Roads and Maritime Supplement to Austroads Guide to Pavement Technology Part 2: Pavement Structural Design
Department for Infrastructure and Transport (South Australia)	• Roads – Master Specification – RD-PV-S1 Supply of Pavement Materials • Supplement to the Austroads Guide to Pavement Technology Part 2: Pavement Structural Design
Department of Transport (Victoria)	• Section 801 Material Sources for the Production of Crushed Rock and Aggregates • Section 812 Crushed Rock for Pavement Base and Subbase • Section 813 Base and Subbase for Lower Trafficked Roads • Section 815 Cementitious Treated Crushed Rock for Pavement Subbase • Code of Practice RC 500.02 Registration of Crushed Rock Mixes

The government agency responsible (State)	Specifications and guides used at the state-level
	• Technical Note 107 Use of Recycled Materials in Road Pavements
Main Roads Western Australia (Western Australia)	• Specification 302 Earthworks • Specification 501 Pavements

IP8-E asserted that the introduction of these specifications has made the use of RCAs more straightforward. As explained by the interviewee, before introducing these specifications, builders seeking to use RCAs had to prepare two separate bids, a conforming bid using virgin materials and a non-conforming bid using RCAs, and subsequently negotiate for using the non-conforming bid. Due to this cumbersome process, not many builders preferred using RCAs before the specifications were introduced.

Compared to the infrastructure sector, building standards and specifications were found to be lagging in this area, and as noted by IP5-A, they need to be amended to accommodate the use of RCMs. According to IP26-C and IP27-A, FWPA has taken a step forward towards this by introducing two interim standards for reprocessed timber, i.e., Recycled Timber – Visually Graded Recycled Decorative Products and Recycled Timber – Visually Stress Graded Recycled Timber for Structural Purposes. However, the interviewees expressed that these interim standards must be reviewed, amended, and developed into formal Australian Standards for broader application. Overall, the interview findings resonated that developing standards and specifications would encourage CPs to consider RCMs when deciding on suitable alternative materials for construction projects.

4.4.2.2.2 Incentivising the use of RCMs

Another approach the government could consider in promoting RCMs is incentivising their use. This can be done by incentivising the use of RCMs in government projects or by using pricing policies that make RCMs more economically attractive compared to virgin alternatives.

Under the first approach, a requirement to use RCMs can be included as a tender evaluation criterion with a higher weightage when calling tenders for government projects. This was supported by IP13-E, who mentioned:

> For projects where there's great opportunities to maximise the use of recycled materials, we can ask contracting and procurement teams to include tender criteria or tender schedules that motivate contractors to use more recycled materials than they might otherwise do.

As revealed through the extract, having such tender criteria would motivate CPs submitting tenders for government projects to reconsider their routine use of common materials and include RCMs in project proposals, thereby increasing the chances of winning the projects. Multiple interviewees noted that most state governments have implemented "Local Industry Participation Plans", which are aimed at measuring the contribution of government projects to the economies of each state. As a part of such plans, tenderers are required to indicate the proportion of a project that would be delivered by or supplied by local businesses within the state, and subsequently, tenders with a higher degree of local industry participation are prioritised when awarding the project. The interviewees noted that a similar approach could be adopted for promoting the use of RCMs in government projects, where tenderers are required to indicate, at the time of tendering, what materials they would substitute with RCMs, the proportions that would be substituted, and from where the materials would be obtained. Based on this information, tenders that propose a higher degree of substitution of virgin materials can be given a higher weightage during tender evaluation. IP13-E noted that this approach is being considered by the Department of Transport and Main Roads – Queensland and the DIT – South Australia as a method to encourage tenderers to use more RCMs and to send prospective tenderers the signal at the tender stage, that furthering the use of RCMs is a crucial area of interest for these government departments. IP13-E and IP15-C also mentioned that once a project is awarded, the use of RCMs can be included as a key result area in the contract. By doing so, the actual use of RCMs by the project team can be assessed against this key result area to reward them further financially.

Under the second approach, pricing policies can be used to make RCMs more economically attractive compared to virgin alternatives. As stated by IP1-E, "*Governments should be a bit more proactive and have some cost benefit*." Alluding to this, IP16-C mentioned that "*Governments must make them* [RCMs] *financially viable*." The interviewees identified two methods that can be used to achieve this: (1) decreasing the cost of using RCMs and/or (2) increasing the cost of using virgin materials. Firstly, to decrease the cost of using RCMs, governments can offer subsidies or rebates for using such materials. For example, the federal government and state and territory governments of the Australian Capital Territory, New South Wales, Northern Territory, South Australia, and Victoria have implemented rebate schemes for promoting rooftop solar and battery systems that significantly reduce the cost of purchasing and installing solar energy systems. IP6-A, IP7-E, and IP21-A noted that similar schemes could also be developed to

incentivise the use of RCMs. As expressed by IP7-E, "*If there were rebates introduced for using certain materials, it'd be interesting to see how that would work (…); I mean, the government's done it with solar panels.*" Secondly, the cost of using virgin materials can be increased by imposing taxes on virgin materials when a reprocessed alternative is readily available. IP28-C mentioned that such taxes could be considered for materials like virgin aggregates, for which there exists a more reliable supply of RCAs. As stated by the interviewee, "*If the government sets a tax on virgin aggregates, I believe it could really help prop up the sale of recycled aggregates*." From the perspective of CPs, such pricing policies would allow them to use RCMs and still stay within the client's budget. Moreover, it would relieve them from the burden of convincing clients not interested in using RCMs to consider using such materials. This follows on from the assertion of IP3-A that monetary benefits are crucial in convincing profit-centred clients to use RCMs; "*There has to be some sort of yield or some sort of monetary benefit that's beyond just, you know, say the altruistic kind of motive of saving the world.*" The study findings reverberated that incentives are a good first step in catalysing the virgin to reprocessed shift and should ideally be considered before resorting to mandates (explained in more detail under Section 4.4.2.2.3).

4.4.2.2.3 Imposing mandates to use RCMs

In the efforts towards improving the uptake of RCMs, the government can impose mandates that require RCMs to be considered when making decisions around materiality. Multiple interviewees noted that unless CPs are forced to change to RCMs, they will generally gravitate towards the more commonly used materials. This was emphasised through the following comment by IP13-E,

> My experience is that they'll only do that [select RCMs] if they are forced to. If we just say you are permitted or allowed to use reprocessed materials as an alternative to traditional materials, then there's no real incentive for them to do that.

Alluding to the above comment, IP10-E stated that "*Unless they* [CPs] *are really forced to, it's never going to happen.*" Within such a background, the interviewees noted that the government must impose mandates that push CPs to shift from virgin materials to RCMs. Herein, mandates can be imposed that require a certain percentage of all materials used for specific projects or applications to be reprocessed. "*Having more regulations in place that make using reprocessed materials compulsory in some applications, I think, will be a step forward*," said IP4-A. This was affirmed by IP25-C, who mentioned that "*There needs to be demand created for these materials* [RCMs] *through minimum quotas or percentages*

on certain projects." The interviewee further acknowledged that such mandates should be imposed gradually and can first target public sector projects over which the government has greater control. Subsequently, the requirements can also be extended to include private-sector projects. IP18-A and IP25-C went on to mention that the increase in demand for RCMs created through such mandates would henceforth lead to the development of industries capable of supplying these materials to the market. According to IP22-E, such mandates further ensure that CPs who prioritise RCMs, even if it results in higher costs, are not disadvantaged when selecting project teams. This is because comparisons will then be based on similar criteria, with the mandatory requirements being established.

The interviewees noted that mandates would also compel clients who are otherwise not interested in pursuing RCMs to accept such materials. IP4-A stressed this point as follows:

> When it [using RCMs] becomes compulsory, there's no room for them [clients] to think about substituting for new materials…Where you don't have a client that's passionate about using reclaimed materials, having those tick-boxes in place that make it compulsory to use different types of reclaimed materials can help us in getting those materials across the line; we don't have to argue as much I suppose to push for that.

The extract further shows that with government-imposed mandates, CPs are relieved from the burden of persuading clients to approve and accept RCMs.

Although mandatory requirements can encourage the use of RCMs, the interviewees expressed that they should be imposed with caution since it might not always be viable to use RCMs, especially for projects in areas without any local supply sources or when there is an unanticipated growth in construction demand. Commenting on the first point regarding limitations with local supply sources, IP13-E mentioned that it would be unwise to use RCMs in such instances partly due to the high transportation costs and partly due to the significant haulage emissions that would offset the environmental benefits of using RCMs. Alternatively, commenting on the second point regarding unanticipated growth in construction demand, IP3-A expressed that the supply of RCMs might be unable to keep up with the demand in such a situation owing to underdeveloped supplies. Therefore, the interviewee expressed that developing the required ecosystem around the supply of RCMs must be considered alongside such mandates; "*You can't make people do something, force people to do something, if there is no supporting ecosystem around it, you are kind of setting people up to fail*," said IP3-A.

The study findings found that mandatory requirements for considering RCMs have been imposed recently in certain government projects, especially in the infrastructure realm. As recalled by IP24-A:

> In some of the larger infrastructure projects, that is already happening, particularly with materials like recycled aggregates and crushed concrete…there's certainly growing requirements to consider reuse and recycling of materials.

One of the key examples highlighted here is the mandatory sustainability initiatives imposed by DIT South Australia through their sustainability specifications introduced in 2019 (updated 2021) (i.e., Master Specification PC-ST1 Sustainability in Design and Master Specification PC-ST2 Sustainability in Construction). As a part of these mandatory sustainability initiatives, CPs undertaking projects for DIT South Australia are required to optimise the use of recycled and recyclable materials. Where that is not viable, they must provide adequate reasonings and justifications to show why that is the case. IP13-E provided a detailed explanation of how these mandatory sustainability initiatives work, as outlined in the following extract:

> The contractor or the consultant doing the design is required to respond to the mandatory sustainability initiatives, so need to assess those mandatory initiatives and determine if they are viable for the project. So, let's say I'm designing a road; I will look at the mandatory initiatives that say recycled crushed concrete, there's a process, a series of questions in the specifications that says is there potential to use the recycled alternative, is it permitted under the specifications, is there a local source of that material. And then they need to do a triple bottom line assessment, so looking at the cost, the benefit, the risk, any impacts on the construction program, and additional cost, and then, yeah, after they've done that assessment, they need to determine whether it can be implemented or not. And if it's not going to be implemented, they need to provide justification for that. So, a bit of a framework is provided for contractors and designers to make that decision.

Apart from the above mandatory sustainability initiatives, which are common for all DIT South Australia projects, specific client nominated sustainability initiatives are explicitly imposed for individual projects, which can also include requirements around the use of RCMs.

Another example of a government-imposed mandate identified is the 'Recycled First' policy of the Victorian Government, enacted in 2020. One of the key objectives of this policy is to optimise the use of recycled and reused materials on Victorian transport infrastructure projects (ecologiQ and Victoria State Government 2020). This mandatory policy requires tenderers competing for transport infrastructure projects to indicate how they would incorporate recycled or reused materials into projects. Successful tenderers

must report against the commitments made to consider recycled first at the tender stage, during project delivery. Overall, the findings indicated that when implemented cautiously, mandates can be a viable strategy for promoting the uptake of RCMs.

4.4.2.2.4 Providing a clear pathway to obtain approvals for using RCMs

The interview findings asserted that authorities responsible for approving materials must support the uptake of RCMs by providing a clear pathway for obtaining approvals for materials not covered by current specifications. IP13-E elaborated on this as follows:

> There should be a process or pathway for people to get approval for materials that aren't covered in specs…if you want to use a material that we're not familiar with and it's not in our specifications, then this is the process that you need to follow, and this is who you ask approval from, just to make it very clear how to go about asking and getting approval."

Unless clear guidelines around the approval process exist, CPs tend to resort to virgin materials, which are easily approved. Alongside providing a clear path for obtaining approvals, IP13-E and IP26-C highlighted that a web-based factsheet could be developed, indicating the maximum allowable percentages of different RCMs that can be used for specific applications. Such a factsheet would clearly indicate the materials that are already approved and the materials for which approvals must be sought.

4.4.2.2.5 Allocating higher credits for using RCMs in sustainability rating systems

With evolving discussions around topics such as climate change, carbon emissions, and environmental conservation, the focus of construction projects on achieving sustainability ratings has increased. The interviewees noted that both public and private sector projects are being increasingly rated against sustainability rating tools such as Green Star, National Australian Built Environment Rating System (NABERS), and ISCA. Interest in achieving sustainability ratings, specifically in public sector projects is growing, with the Australian Government's target of reaching net zero emissions by 2050. For example, IP8-E and IP10-E highlighted that some states require large-scale infrastructure projects to obtain a rating under the ISCA rating tool. Similarly, IP5-A and IP11-C expressed that government organisations are focusing on achieving ratings, such as NABERS or Green Star, for their tenancy spaces. According to the interviewees, private sector projects, especially commercial and residential developments, are also targeting these ratings because they act as marketing tools for attracting environmentally conscious tenants.

With this growing interest in sustainability ratings, the interviewees emphasised that allocating a higher weightage for sustainable material use in rating tools with a specific

focus on RCMs would encourage CPs to push for the use of such materials. As expressed by IP23-A:

> Continued recognition of reprocessed materials in rating systems, things like Climate Active and Green Star, is kind of key to improve this, and I think that'll be a definite good outcome.

IP23-A, an experienced ESD consultant, stated that most rating tools currently focus on minimising operational emissions, which does not relate directly to using RCMs. However, if more rating tools incorporated requirements around minimising embodied emissions as an assessment criterion, CPs would be encouraged to use RCMs with low embodied emissions to meet that requirement. The requirement of the Green Star rating tool to undertake whole-life analyses of projects was highlighted as a promising development in this regard since it requires demonstrating the reduction of embodied emissions, which could be achieved through the use of RCMs.

4.4.3 Summary of strategies for promoting the uptake of reprocessed construction materials among construction professionals

Table 4.4 below provides a detailed summary of the strategies for promoting the uptake of RCMs among CPs identified through the interview findings. Following Table 4.4, Figure 4.6 provides a concise summary of the factors limiting the uptake of RCMs among CPs (explained in Section 4.3) and the strategies for promoting the uptake of RCMs among CPs (explained in Section 4.4), identified as outcomes of the qualitative survey.

Table 4.4: Summary of the strategies for promoting the uptake of reprocessed construction materials among construction professionals

Strategy Classification		Strategy	Strategy explanation
Informational strategies	Information and education strategies	Bringing external expertise into design and construction teams	• Obtaining the service of external experts (e.g., ESD Consultants) to encourage and support CPs in using RCMs • Experts can convince CPs of the significance of environmental focus in material selection and provide expert advice on RCMs (i.e., market availability, prior research, potential applications, and limitations) • Expert input can help address knowledge gaps among CPs and minimise perceived risks
		Sustainability forums at the organisational level for knowledge sharing	• Establishing organisation-wide sustainability forums to share knowledge about sustainability initiatives, including the use of RCMs • This provides a platform for CPs to improve their understanding of RCMs • These forums facilitate the dissemination of knowledge which would otherwise stagnate within individual professionals • They can also serve as a conduit for knowledge sharing between external sustainability bodies and CPs employed within organisations
		Effective marketing of RCMs	• Improving marketing to provide the required information for selecting RCMs promptly • Marketing efforts must focus on providing information on availability, costs, testing results, certifications, environmental benefits, and previous applications • Both physical and electronic marketing methods can be used
		Educating students on the use of RCMs as part of curricula	• Educating CPs on using RCMs as a part of curricula, thereby laying the foundation for them to expand their knowledge later through practice • Should focus on two areas: (1) the importance of considering environmental impacts and alternative material options in general, and (2) knowledge and skills specific to the use of RCMs • More focus is needed in curricula for builders since they exhibit a lower degree of awareness compared to architects and engineers
		Initiatives for raising awareness regarding RCMs	• Raising awareness among CPs regarding RCMs and the importance of considering such alternative environmental-friendly material options

Strategy Classification	Strategy	Strategy explanation
		• At the governmental level, these initiatives can include forums for knowledge sharing (e.g., conferences, talks/presentations), developing guidance materials, and providing specialist advice • At the non-governmental level, these initiatives can include CPDs targeting the use of RCMs, forums for knowledge sharing, and developing guidance materials
	Developing a centralised database for RCMs	• Developing a centralised database to provide quick and easy access to information on RCMs offered by different suppliers in the market • Should ideally be in an electronic format (i.e., website or mobile application), user-friendly and easy to navigate, and updated regularly • Include information on materials available, costs, supplier details and locations, material grades and performance levels, testing results, and environmental data
Modelling strategies	Modelling the use of RCMs through reference projects	• Demonstrating practical applications and benefits of using RCMs through reference projects, thereby encouraging CPs to adopt similar methodologies • Some government infrastructure projects are already using RCMs, and learnings from such projects can be shared across the industry • A reporting tool must be developed to capture information on the types and volumes of RCMs used in different projects so that it can serve as a knowledge repository for future projects to draw from
Commitment strategies	Encouraging CPs to commit towards using RCMs	• Encouraging CPs to make written public commitments to use RCMs, thus increasing their likelihood of following through with the commitment and taking action to increase the use of RCMs
Feedback strategies	Developing tools to provide feedback on the positive environmental impacts of using RCMs	• Developing tools to calculate environmental impact indicators such as carbon emissions associated with using different RCMs and virgin materials • This would enable CPs to see the environmental benefits of using RCMs over virgin materials and thereby prompt them to consider RCMs during the material selection
Credibility-building strategies	Strengthening the credibility of RCMs	• Improving confidence in the use of RCMs through the provision of reliable information from trusted sources

Strategy Classification		Strategy	Strategy explanation
			• Research was recognised as a pivotal aspect in building credibility for RCMs
Structural strategies	Infrastructural strategies	Embedding sustainable material use as a priority consideration in the methodology of design and construction organisations	• Encouraging CPs to consider RCMs during material selection by embedding sustainable material use as a priority consideration in the organisation's methodology
		Enhancing the cost competitiveness of RCMs	• This involves ensuring that the costs of RCMs are comparable to virgin alternatives • Waste processors must look at alternative waste recovery methods that are convenient, less costly, and efficient
		Assuring the quality of RCMs	• This involves ensuring that RCMs have superior and consistent quality • The importance of rigorous testing regimes, product certification, and performance guarantees was reiterated to ensure that RCMs are of acceptable quality, meet industry standards, and are readily approved for construction and insurance purposes • Through rigorous testing, suppliers could drive relevant authorities to include RCMs in industry specifications • Waste processors can opt for third-party quality certifications such as ISO 9001 to ensure process and output quality
		Ensuring reliable supplies of RCMs	• This involves (1) ensuring that sufficient quantities of RCMs are available and (2) ensuring that materials can be sourced consistently • Reasonably large material stocks must be maintained to ensure that RCMs can be sourced from a single source without experiencing any stockouts • A steady stream of supply must also be maintained to enable sourcing RCMs consistently, on-demand
		Developing systems to facilitate	• This involves developing systems to track the origins of RCMs to inform future uses and mitigate the risks of quality failures associated with using materials from unknown origins

Strategy Classification	Strategy	Strategy explanation
	traceability of RCMs to prior uses	• Traceability is especially important when opting for sustainability ratings such as Green Star and LEED, which demand a good audit trail of materials • Building Information Modelling (BIM), digital twins, and Radio Frequency Identification (RFID) can be enabling technologies for material tracking
Legislative and policy strategies	Developing standards and specifications for RCMs	• Involves developing standards and specifications targeting RCMs to facilitate their use • Standards and specifications must be tailored for RCMs since there are specificities associated with using RCMs, that might not apply to using virgin alternatives • Standards and specifications for RCMs should be more relaxed and offer a wider window of performance compared to virgin materials • Specifications should be performance-based rather than recipe/prescriptive-based to allow a more comprehensive range of materials to be considered • Standards and specifications should be developed ideally at the national level to ensure their applicability across multiple jurisdictions • Infrastructure specifications have become more attuned to RCMs; however, building standards and specifications were found to be lagging in this area and must, therefore, be amended to accommodate RCMs
	Incentivising the use of RCMs	• This involves incentivising the use of RCMs in government projects or using pricing policies that make RCMs more economically attractive compared to virgin alternatives • The requirement to use RCMs can be included as a tender evaluation criterion with a higher weightage when calling tenders for government projects, thereby motivating CPs to consider RCMs when tendering for government projects • The use of RCMs can be included as a key result area in contracts, and project teams can be assessed against it and rewarded financially • Pricing policies can be used to (1) decrease the cost of using RCMs (e.g., subsidies or rebates for using RCMs) and/or (2) increase the cost of using virgin materials (e.g., imposing taxes on virgin materials)

Strategy Classification	Strategy	Strategy explanation
	Imposing mandates to use RCMs	• Imposing mandates that require RCMs to be considered when making decisions around materiality • Mandates can be imposed that require a certain percentage of all materials used for specific projects or applications to be reprocessed • To be implemented gradually – first for public-sector projects over which the government has more control and subsequently extended to private-sector projects • Should be imposed with caution since it might not always be viable to use RCMs, especially for projects in areas without any local supply sources or when there is an unanticipated growth in construction demand
	Providing a clear pathway to obtain approvals for using RCMs	• Providing a clear pathway for obtaining approvals for RCMs not covered by current specifications – should identify the process to be followed and the responsible approval bodies • A web-based factsheet could be developed, indicating the maximum allowable percentages of different RCMs that can be used for specific applications – to identify approved materials and materials for which approvals must be sought
	Allocating higher credits for using RCMs in sustainability rating systems	• Allocating a higher weightage for sustainable material use in sustainability rating systems with a specific focus on RCMs would encourage CPs to consider the use of such materials • This is especially useful with both private and public sector projects increasingly opting for sustainability ratings

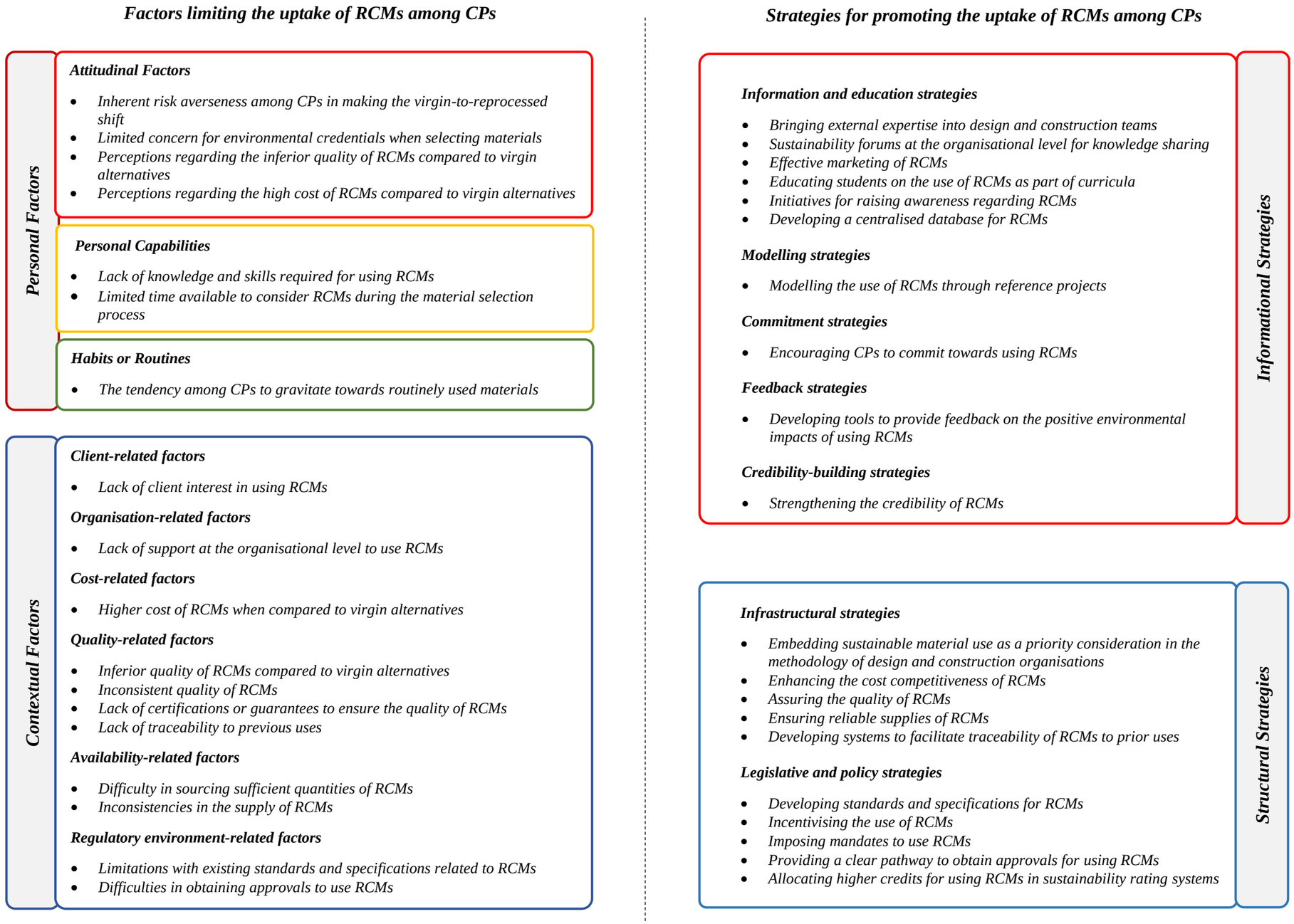


Figure 4.6: Summary of limiting factors and strategies for promoting the uptake of reprocessed construction materials among construction professionals

4.4.4 Mapping the strategies for promoting the uptake of reprocessed construction materials with the stakeholders of the reverse logistics supply chain for demolition waste

Figure 4.6 provides a visual representation of the strategies for promoting the uptake of RCMs, mapped against the stakeholders of the DW RLSC responsible for implementing them. This mapping serves to highlight the role of different stakeholders in the RLSC for DW in promoting the uptake of RCMs among CPs. The stakeholders are grouped into four main categories: design and construction organisations, waste processors (suppliers of RCMs), government, and interest aggregators. Interest aggregators are further classified into two sub-categories: educational institutes and non-governmental bodies. The non-governmental bodies are then subdivided into sustainability organisations and professional institutes, as certain strategies are specifically attributed to these particular sub-groups of stakeholders.

It is worth noting that although demolition contractors and landfill operators were acknowledged as stakeholders within the DW RLSC in Section 2.5, no strategies were identified during the interviews that directly relate to these two groups. This could be because these stakeholders do not interact directly with end users of RCMs. Furthermore, although design and construction organisations were not explicitly identified as a distinct stakeholder group within the DW RLSC in Section 2.5, the study findings underscored their significant role in promoting the uptake of RCMs among CPs since CPs work within these organisations. It became evident that design and construction organisations can play a crucial role in advocating for and facilitating the uptake of RCMs among CPs.

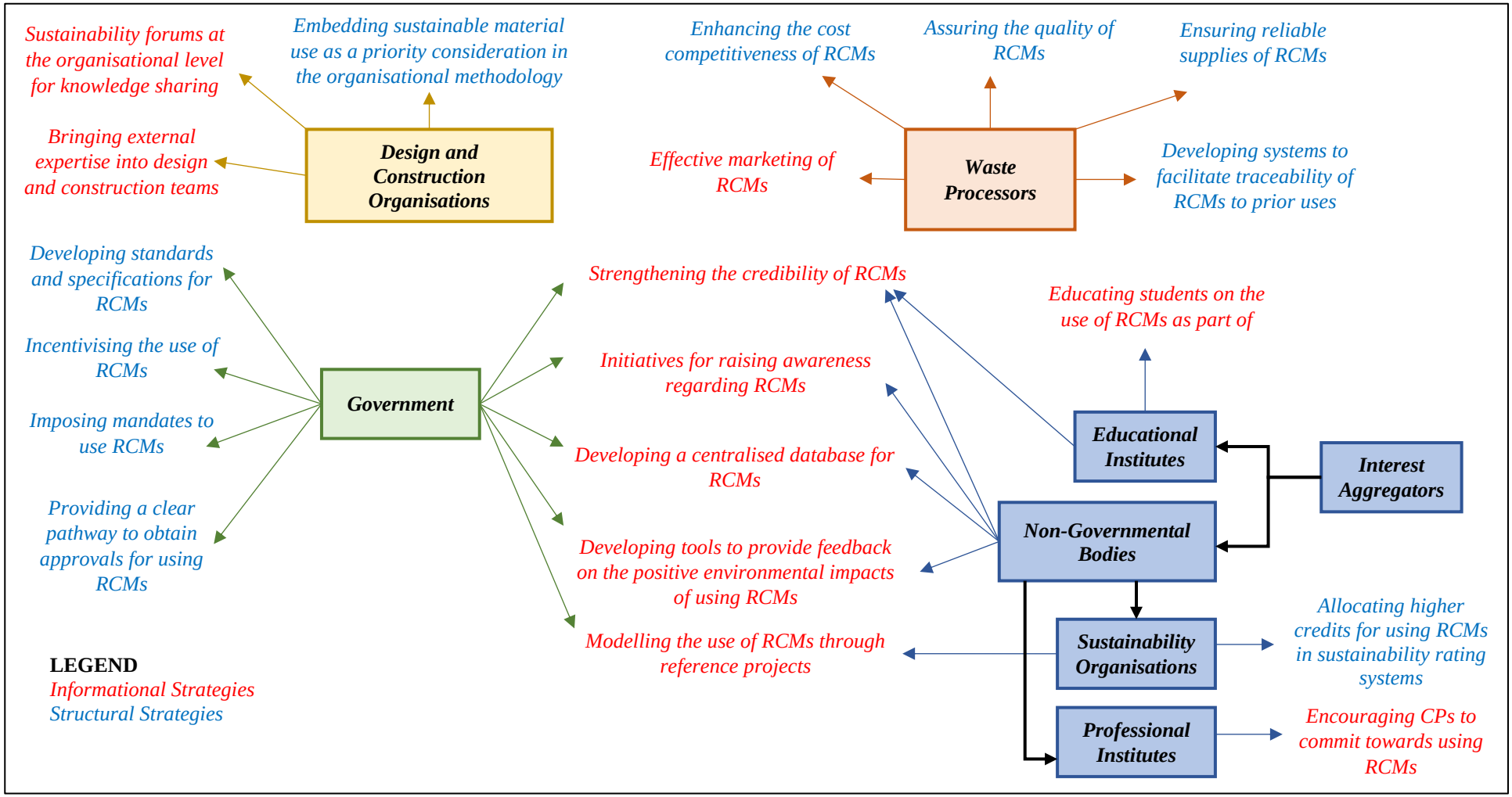


Figure 4.7: Mapping the strategies for promoting the uptake of reprocessed construction materials among construction professionals against responsible stakeholders

4.5 Chapter summary

Aligned with the first and second objectives of the study, this chapter focused on identifying potential factors that limit the uptake of RCMs among CPs and possible strategies for promoting the uptake of such materials. Thirty-one semi-structured interviews were conducted with CPs involved in material selection decisions and having prior experience with using RCMs. As supported by ABC Theory, the study findings showed that multiple personal and contextual factors could limit the uptake of RCMs among CPs within the Australian construction industry. Following this, multiple informational and structural strategies that could be used for promoting the uptake of RCMs among CPs were also identified. These strategies were found to require the efforts of different stakeholder groups within the RLSC for DW for their successful implementation and were therefore mapped against the stakeholders responsible for implementing them. Interestingly, the findings revealed that, following the advancements made in their recovery process, RCAs are more readily used by CPs when compared to other RCMs. Therefore, the next chapter takes a detailed look into the process of producing RCAs from DW to better understand how waste processors could structure DW recovery processes in a user-centric manner to meet the requirements of CPs.

CHAPTER FIVE: FINDINGS – CASE STUDIES

5.1 Introduction

The purpose of this chapter is to explore how waste processors could structure demolition waste (DW) recovery processes in a user-centric manner to meet the requirements of construction professionals (CPs). Herein, case studies were undertaken with three waste processing companies that produce recycled concrete aggregates (RCAs) from DW, representing a current industry best practice in DW recovery in Australia. The measures taken by these companies in structuring their DW recovery processes to meet the requirements of CPs were explored in-depth through the case studies. Based on these findings, a best-practice framework for a user-centric DW recovery process was developed and validated, as explained in detail in this chapter.

5.2 Focus areas for a user-centric demolition waste recovery process

As established through the introduction and literature review of this study, it is important to understand how waste processors can structure DW recovery processes in a user-centric manner to meet the requirements of CPs, which would, in turn, lead to increased user satisfaction and a higher uptake of RCMs. In doing so, it is important first to identify the requirements expected by CPs from waste processors in order for them to incorporate RCMs into their projects. The findings from Phase I of the study, which investigated strategies for promoting the uptake of RCMs among CPs, highlighted five specific requirements that CPs expect from waste processors. These include:

1. **Effective marketing of RCMs** – CPs expect waste processors to provide the required information for selecting RCMs promptly
2. **Enhancing the cost-competitiveness of RCMs** – CPs expect waste processors to ensure that the costs of RCMs are comparable to virgin alternatives
3. **Assuring the quality of RCMs** – CPs expect waste processors to ensure that RCMs have superior and consistent quality

4. **Ensuring reliable supplies of RCMs** – CPs expect waste processors to ensure that sufficient quantities of RCMs can be sourced consistently
5. **Traceability of RCMs to prior uses** – CPs expect waste processors to develop systems to trace RCMs to their prior uses

Consequently, these five areas were identified as five focus areas to be considered by waste processors when structuring DW recovery processes in a user-centric manner to meet the requirements of CPs. In this research, these five focus areas were conceptualised as five sides of a hierarchical pyramid, delineating the structuring of a user-centric DW recovery process, as depicted in Figure 5.1. According to the figure, the uppermost tier represents the goal of structuring DW recovery processes to be user-centric, which would lead to increased user satisfaction and a higher uptake of RCMs. The second tier represents the aforementioned five focus areas that waste processors must concentrate on in achieving the goal of structuring DW recovery processes to be user-centric. The third tier represents the specific measures that the waste processors should take to achieve the focus areas. These measures are explored in detail in this phase of the study using a case study approach, where case studies were undertaken with three waste processing companies that produce RCAs from DW, representing a current industry best practice in DW recovery in Australia. The justification for selecting waste processing companies that produce RCAs from DW is further elaborated in the following section.

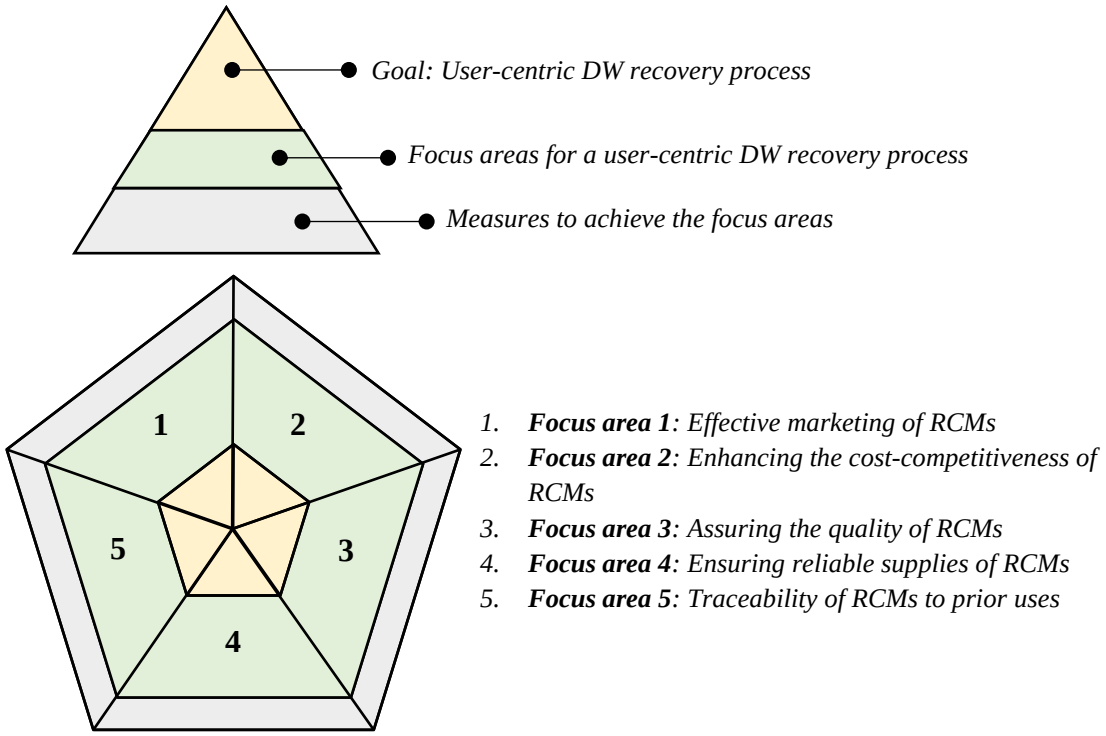


Figure 5.1: User-centric demolition waste recovery as a hierarchical pyramid

5.3 Producing recycled concrete aggregates from demolition waste – An industry best practice in demolition waste recovery

Findings from Phase I revealed that CPs exhibit a higher tendency to accept and use RCAs compared to other RCMs. This observation is consistent with the Australian National Waste Report 2020, which identified the existence of favourable markets for RCAs, mainly used as roadbase materials and as aggregates in new concrete mixes (Pickin et al. 2020). In addition, Sustainability Victoria's market analysis on recycled concrete affirmed this finding, revealing that markets for RCAs are generally more established compared to materials like recycled bricks, particularly in metropolitan areas (Sustainability Victoria 2014). According to a recent report by the Sustainable Built Environment National Research Centre (SBEnrc) Australia, RCAs account for approximately 60% of all masonry material recycled in Australia, with more than six million tonnes of concrete waste recycled annually (Maqsood et al. 2020). Moreover, the Victorian Recycling Industry Annual Report – 2018/19 highlighted that RCAs accounted for the highest tonnage of all materials recovered from different waste streams in Victoria during 2018/19, suggesting a higher utilisation of RCAs in construction applications (Sustainability Victoria 2020). Data presented in Figure 5.2 further supports this claim and highlights a notable increase of

approximately 35% in the tonnage of concrete waste recovered to be processed primarily into RCA-based materials in Victoria from 2015 to 2020.

As indicated through the above findings, the increased production and use of RCAs suggest that these materials have successfully met user requirements. Therefore, it can reasonably be argued that the process of producing RCAs from DW represents a current industry best practice in DW recovery in Australia. Consequently, under the second phase of the study, case studies were undertaken with three Australian waste processing companies (Company A, Company B and Company C) that produce RCAs from DW to understand how they have structured their processes to meet the requirements of CPs. The learnings from these case studies were used to develop and validate a best-practice framework for a user-centric DW recovery process, which outlines the measures that waste processors can take for structuring DW recovery processes to meet the requirements of CPs.

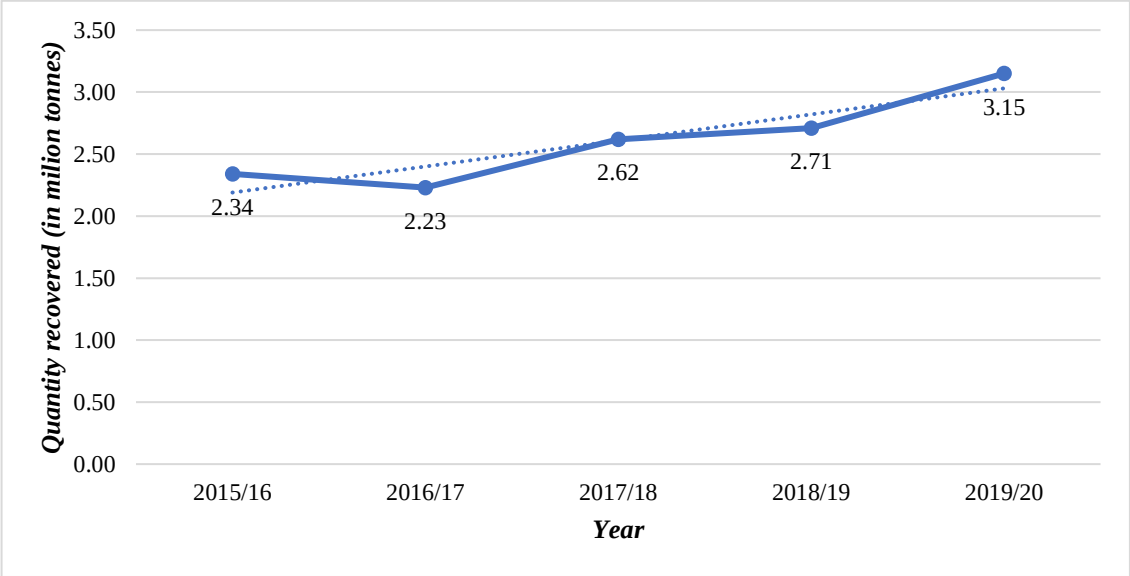


Figure 5.2: Tonnage of concrete waste recovered to be reprocessed in Victoria from 2015-2020 (Source: Developed by the author based on data from Victoria's waste project model dashboard made available by Recycling Victoria)

5.4 Introduction to the case study companies

This section provides an introduction to the three companies selected for the case studies. Background information regarding each case study company is provided, followed by details regarding data collection and an outline of the DW recovery process followed at each company.

5.4.1 Company A

Company A is the largest processor of DW in South Australia. Established in 1992, the company has over thirty years of experience reprocessing DW into usable construction materials. Despite commencing its operations as a processor of DW, the company has now diversified into multiple business areas and operates under four business pillars: DW or the recycling and waste pillar, waste-to-energy or the Process Engineered Fuels (PEFs) pillar, tyre recycling pillar, and the material solutions pillar. The current study focused only on the DW recovery side of the business since the purpose of conducting the case studies was to analyse the DW recovery process.

Company A operates two EPA-licensed and authorised MRFs in South Australia for reprocessing DW. One facility is located at Wingfield (north of Adelaide, the capital city of South Australia), and the other is at Lonsdale (south of Adelaide). The Wingfield facility processes approximately 650,000 tonnes of waste materials annually, while the Lonsdale facility processes approximately 250,000 tonnes. These two facilities convert around 900,000 tonnes of DW annually into RCAs, predominantly used for road construction and concreting applications. The company employs 75-100 employees to manage the DW recovery process. More than 90% of all DW received at the two facilities is recovered. Table 5.1 identifies the types of waste materials accepted for reprocessing and the different RCA-based output materials sent to the market. Company A also has an EPA-licensed and authorised landfill facility in South Australia for disposing of any residual waste from reprocessing and contaminated waste that cannot be processed.

Table 5.1: Waste materials accepted and output materials - Company A

Waste materials accepted	RCA-based output materials
• Clean concrete (concrete with minimum foreign materials (<5%) but can contain reinforcement) • Clean concrete – Oversized (Clean concrete but sizes large than 600mm, mainly footings and large slabs) • Unclean concrete (concrete mixed with foreign materials (e.g., bricks, timber, plastics, soil)	• 10mm and 20mm concrete aggregates, intended for use in manufacturing sustainable green concrete as an alternative to quarried materials • PM 1/20 RM or 40 Base course - Class 1 pavement materials intended for use as pavement layers on high-trafficked roads • PM 2/20 RG or 40 Subbase – Class 2 pavement materials intended for use in pavement layers on medium-trafficked roads or sub-base layers on high-trafficked roads • 10mm and 20mm drainage aggregates - suitable for use as drainage aggregates in backfill behind retaining walls and other drainage aggregates applications

Company A operates across all market sectors and supplies materials for residential, commercial, industrial, and infrastructure projects. Some notable civil and infrastructure projects in South Australia supplied by Company A include the Adelaide Desalination Plant, the Port River Expressway, the Northern Expressway, the Darlington Road Upgrade, Techport Australia, the Aldi Distribution Centre and the Flinders Ports. Company A is also a pioneer in producing carbon credits in Australia and is the first company to be registered under the Emissions Reduction Fund[2].

5.4.1.1 Details regarding data collection – Company A

Data collection was carried out using document reviews (company documents, company website, and social media profiles (i.e., LinkedIn and YouTube)), and this data was verified using semi-structured interviews while gathering additional data about the company's operations. The profiles of the interviewees who participated in the semi-structured interviews are presented in Table 5.2.

Table 5.2: Profile of Interviewees from Company A

Code	Designation	Experience*	Role
CSA-P1	Director of Corporate Affairs and Sustainability	02 years/ (20+ years)	Responsible for sustainability transformation within the company and is involved in sustainability strategy development and sustainability reporting
CSA-P2	Strategic Business Development Manager	12 years/ (18 years)	Responsible for innovation and future projects, which involves looking at ways to divert materials further from landfills and introducing new technologies that can be used to improve the business and its processing capabilities
CSA-P3	Manager of Environmental Development	01 year/ (13 years)	Works with sales teams to identify new market opportunities for existing materials and the potential for introducing new materials
CSA-P4	Health, Safety, Environment, and Quality (HSEQ) Manager	02 years/ (16 years)	Responsible for ensuring compliance with health, safety, environment, and quality requirements and certifications
CSA-P5	Operations Manager – C&DW Recovery	13 years/ (13 years)	Responsible for managing waste recovery processes at the company's MRF at Wingfield
CSA-P6	Sales and Customer Service Manager	05 years/ (08 years)	Responsible for coordinating the inflow of waste materials for reprocessing and the sale of processed materials

**Experience – years of experience in Company A/ (Overall work experience in related roles)*

[2] "The Emissions Reduction Fund provides businesses with the opportunity to earn Australian carbon credit units for every tonne of carbon dioxide equivalent a business stores or avoids emitting through adopting new practices and technologies" (Taken from: Australian Government 2023, Financial Incentives for Businesses to Reduce their Carbon Emissions).

5.4.1.2 An outline of the demolition waste recovery processes followed at Company A

The basic DW recovery process followed at Company A is presented in Figure 5.3 below.

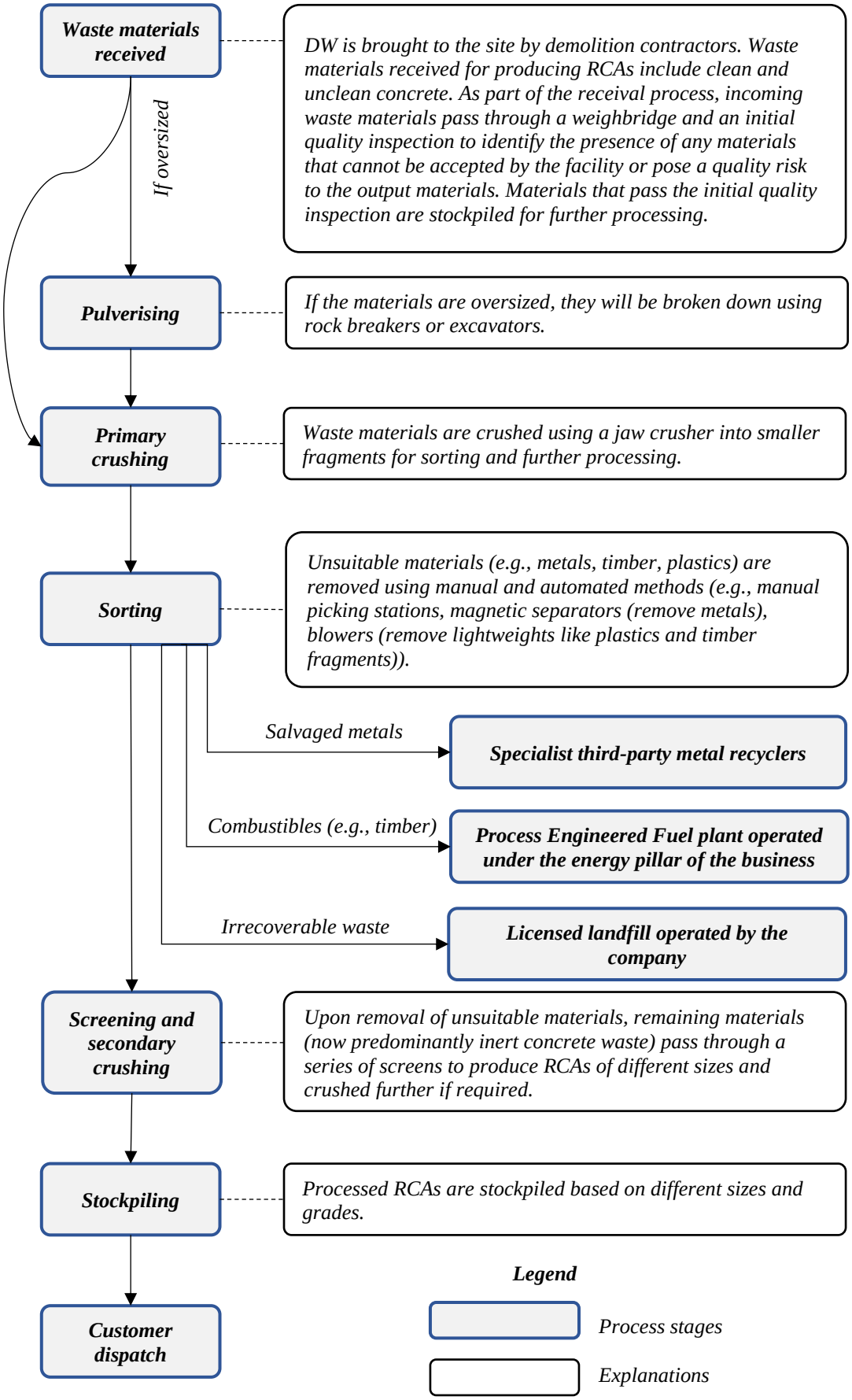


Figure 5.3: Demolition waste recovery process followed at Company A

5.4.2 Company B

Company B is a leader in supplying reprocessed civil construction materials in Australia and has been operating in the field of DW recovery for over three decades. Originally a mining company, it redirected its focus and ventured into the waste processing industry. It has since grown to become a large-scale waste processor with three MRFs spread across Victoria. To date, Company B has diverted over forty-five million tonnes of DW away from landfills to be used in over 240 major projects. In January 2018, Company B was acquired by a globally recognised construction and building material supplier in Australia. Despite this, Company B continues to operate as an independent business entity dedicated to transforming waste that would otherwise have been disposed of in landfills into valuable resources.

Company B operates three EPA-licensed and authorised MRFs in Victoria, located in Clarinda, Epping, and Laverton. Collectively, these facilities have the capacity to reprocess approximately 1.5 million tonnes of DW into RCAs per annum, which are predominantly used for infrastructure projects. The three facilities employ around 100-125 employees to manage the DW recovery process. Company B has achieved very high recovery rates for DW of over 95% through its innovative and well-organised recovery processes. Table 5.3 identifies the types of waste materials the company accepts for reprocessing and the different RCA-based output materials sent to the market. Company B also has an EPA-licensed and authorised landfill facility for disposing of any residual waste from reprocessing.

Table 5.3: Waste materials accepted and output materials - Company B

Waste materials accepted	RCA-based output materials
• Clean concrete (concrete with minimum foreign materials but can contain reinforcement • Mixed concrete (predominantly containing concrete and brick)	• 5mm and 10mm recycled concrete aggregates – intended for use as concrete aggregates, drainage aggregates, road base, fill material, backfill, bedding, and sewer and water pipes • 20mm recycled concrete aggregate – intended for use in rock or block retaining walls and under concrete as a drainage layer • 75mm recycled concrete aggregates – intended for use as backfill, drainage aggregates, wet area access, and cross-over material • 20mm Class 2, 3 and 4 recycled crushed concrete and 40mm Class 3 recycled crushed concrete – intended for use as road bases, hard-stand areas under concrete slabs, and backfilling or bedding materials

Company B has supplied their materials to prominent infrastructure projects in Victoria, including several level crossing removals and Northern, Southern, and Western Road Upgrades. Company B is also a major supplier to Victoria's Big Build projects, which focus on prioritising the use of RCMs. The company has won multiple awards in recognition of its contribution towards the supply of sustainable construction materials in Victoria.

5.4.2.1 Details regarding data collection – Company B

Data collection was carried out using document reviews (company documents, company website, and social media profiles (i.e., LinkedIn, YouTube, and Instagram)), and this data was verified using semi-structured interviews while gathering additional data about the company's operations. The profiles of the interviewees who participated in the semi-structured interviews are presented in Table 5.4.

Table 5.4: Profile of Interviewees from Company B

Code	Designation	Experience*	Role
CSB-P1	National Sustainability Manager	02 years/ (12 years)	Responsible for managing sustainability initiatives across the business, covering five priority areas: CO_2, recycling, biodiversity, water, and corporate social responsibility The interviewee currently works for the parent company of Company B, a leading concrete product supplier in Australia and had been working in Company B for 02 years before being promoted to the parent company
CSB-P2	General Manager	06 years/ (22+ years)	Responsible for overseeing and coordinating the overall business activities of the organisation
CSB-P3	Corporate Communications Manager	05 years/ (22+ years)	Responsible for managing communications, messaging, and engagement with different audiences, internally within the organisation and externally with customers, community groups, and the government
CSB-P4	Recycling Manager	01 year/ (14 years)	Responsible for looking at avenues for improving the waste recovery process and opportunities for business expansion while assisting the sustainability manager in rolling out sustainability initiatives across the organisation
CSB-P5	Sustainable Products Technical Manager	01 year/ (07 years)	Responsible for product development and managing quality and environmental compliance requirements

Code	Designation	Experience*	Role
CSB-P6	Site Supervisor	02 years/ (05 years)	Responsible for day-to-day site supervision (Clarinda MRF)

**Experience – years of experience in Company B/ (Overall work experience in related roles)*

5.4.2.2 An outline of the DW recovery process followed at Company B

The basic DW recovery process followed at Company B is presented in Figure 5.4 below.

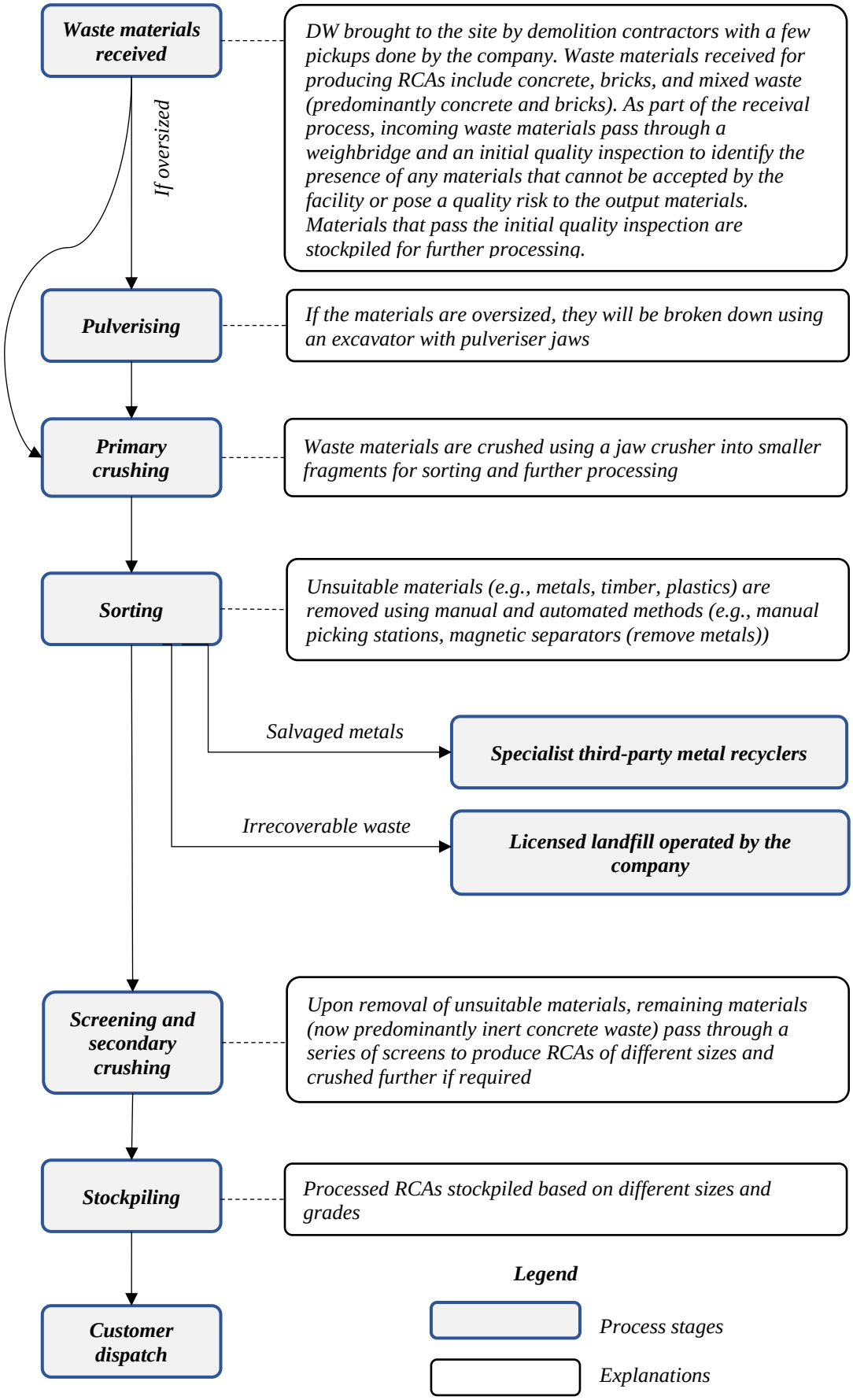


Figure 5.4: Demolition waste recovery process followed at Company B

5.4.3 Company C

Company C is an EPA-licensed and authorised waste processor based in South Australia. The company operates a MRF at the Wingfield Eco Resource Management Centre of the Adelaide City Council. With operations commencing in 2005, the company has since grown to become one of the key processors of DW in South Australia. The Wingfield MRF accepts around 800,000 tonnes of DW annually, primarily including concrete and mixed DW. These waste materials are then reprocessed into RCAs of different grades and sold to building and infrastructure products throughout South Australia. Company C also has a commercial and industrial waste (e.g., cardboard and plastics) reprocessing arm, but it was not studied here since the purpose of conducting the case studies was to analyse the DW recovery process. The company employs 70-80 employees to manage the DW recovery side of the business.

Through their comprehensive waste recovery process, the company has achieved a high waste recovery rate for DW of around 90%. Table 5.5 identifies the types of waste materials accepted for reprocessing and the different RCA-based output materials sent to the market by Company C.

Table 5.5: Waste materials accepted and output materials - Company C

Waste materials accepted	RCA-based output materials
1. Clean concrete (Concrete that is free from soil or other waste materials but contains any amount of reinforcing steel/mesh) • *Concrete small* – Less than 400mm in all dimensions • *Concrete large* – Concrete slabs larger than 400mm 2. Mixed concrete (Concrete containing foreign materials such as bricks, timber, and plastics)	1. Concrete aggregates – Used as a virgin aggregate replacement in concrete mixtures 2. PM 1/20 RM or 40 base course material suitable for upper layers of high to medium-traffic roadways) 3. PM 2/20 RG or 40 sub-base course material suitable for sub-layers of roadways 4. PM 3/20 RG or 40 sub-base course material suitable for all lower layers of roadways 5. Screened material (7-14mm, 14-20mm, and 14-40mm) suitable for use as drainage and bedding materials, including pipe bedding

The company caters to the material requirements of building and infrastructure projects throughout South Australia and has supplied some of the state's large-scale road and bridge construction projects and retail precincts.

5.4.3.1 Details regarding data collection – Company C

Data collection was carried out using document reviews (company documents and company website), and this data was verified using semi-structured interviews while gathering additional data about the company's operations. The profiles of the interviewees who participated in the semi-structured interviews are presented in Table 5.6.

Table 5.6: Profile of Interviewees from Company C

Code	Designation	Experience*	Role
CSC-P1	General Manager	15 years/ (18 years)	Responsible for overall company management, including establishing organisational policies and strategies and people management
CSC-P2	Sales Manager	07 years/ (20 years)	Responsible for managing sales and assisting with day-to-day operations of the company, including staffing and waste classification
CSC-P3	Operations Manager	08 years/ (08 years)	Responsible for managing on-site waste recovery operations of the company
CSC-P4	Weighbridge Operator	04 years/ (04 years)	Responsible for monitoring material inflows and outflows at the weighbridge
CSC-P5	Sales Executive	04 years/ (09 years)	Responsible for liaising with customers and marketing RCAs
CSC-P6	Site Supervisor	05 years/ (12 years)	Responsible for overseeing and coordinating daily site operations

**Experience – years of experience in Company C/ (Overall work experience in related roles)*

5.4.3.2 An outline of the DW recovery process followed at Company C

The basic process of converting DW into RCAs followed at Company C is presented in Figure 5.5.

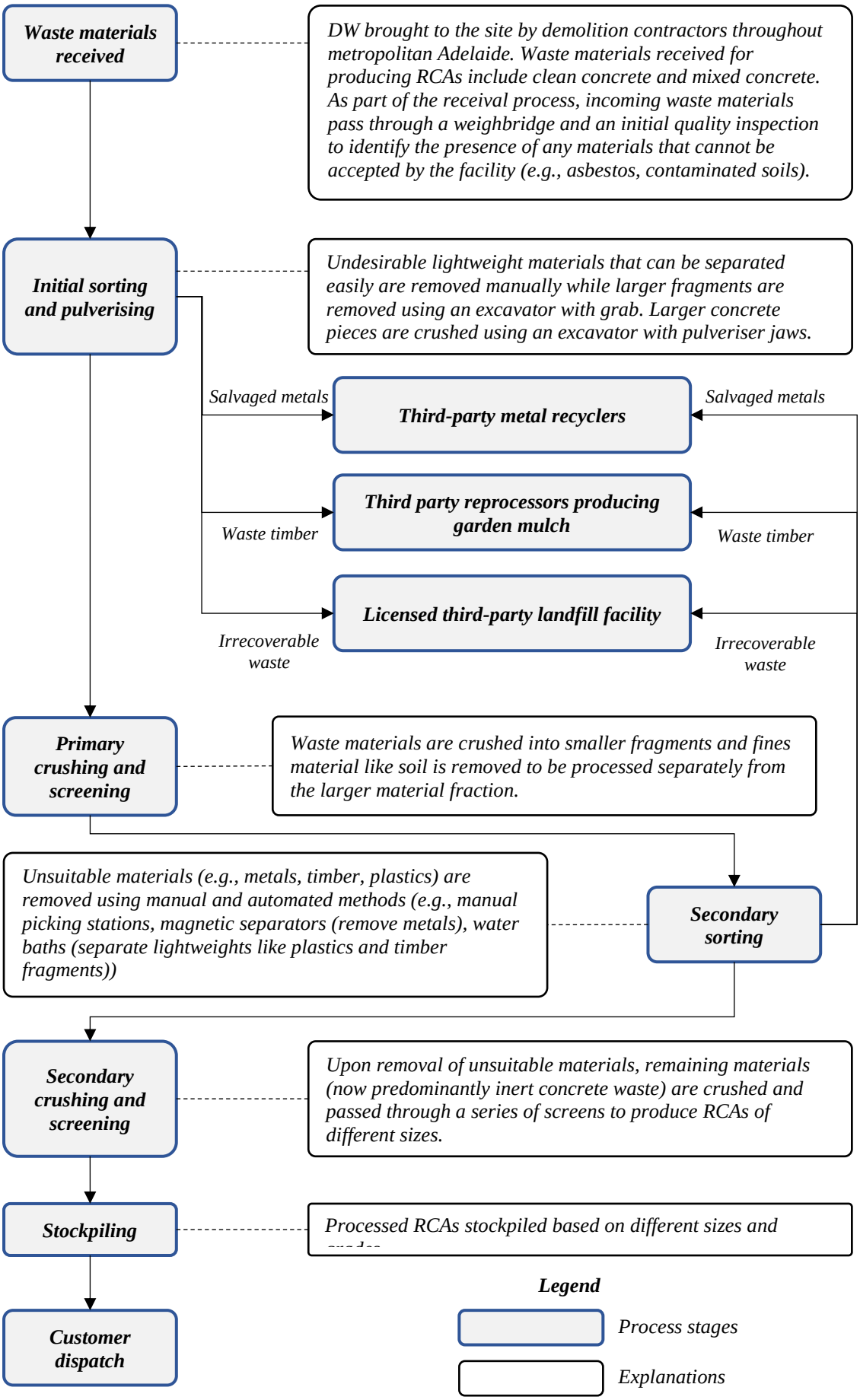


Figure 5.5: Demolition waste recovery process followed at Company C

5.5 Measures taken by case study companies to structure demolition waste recovery processes to meet the requirements of construction professionals

The measures taken by the case study companies in structuring their processes in a user-centric manner to meet the requirements of CPs are presented in this section. Herein, five focus areas were considered (as explained in Section 5.2), and the measures taken by the selected companies under each of these five focus areas are elaborated in detail.

5.5.1 Focus area 1: Measures taken for effective marketing of the outputs

The findings revealed that the case study companies had used a multitude of measures to effectively market their outputs, which could be broadly categorised into physical channels, electronic channels, and printed channels. These measures are shown in Figure 5.6.

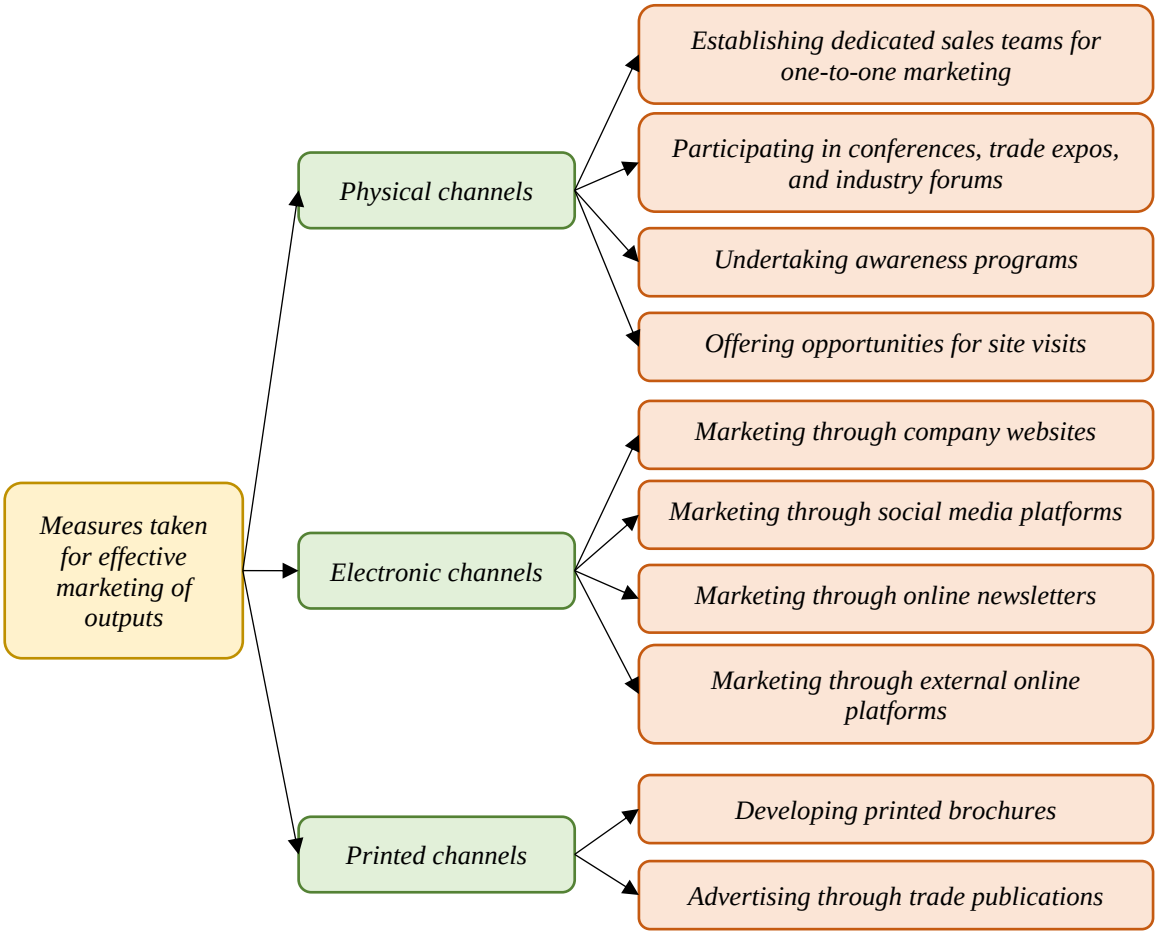


Figure 5.6: Measures taken for effective marketing of outputs

5.5.1.1 Physical channels

Under physical channels, the findings revealed that the case study companies had adopted four measures, which include establishing dedicated sales teams for one-to-one marketing, participating in conferences, trade expos, and industry forums, undertaking awareness programs, and offering opportunities for site visits. These measures are explained in detail in the following sections.

5.5.1.1.1 Establishing dedicated sales teams for one-to-one marketing

As a primary means of marketing their materials, all three companies have established dedicated sales teams for one-to-one marketing. These sales team members are commonly referred to as "Account Managers" across all three companies. Such individualised, one-to-one marketing is considered significant, given that procurement of materials in the construction industry relies heavily on word-of-mouth methods and industry relationships. CSA-P6 from Company A elaborated on this aspect as follows:

> The industry is a lot of word-of-mouth and building relationships, and if you can't build relationships, then it just doesn't work. So, the sales team are on the phone, all day long, talking to customers.

Adding to this, CSB-P3 from Company B noted,

> We have a sales team that are very active in building relationships with key customers, and potential customers, so that's probably first and foremost…they partner with customers to make sure that we're very aware of what their needs are and that we can deliver on their expectations.

Elaborating further on the positives of one-to-one marketing, CSC-P5 mentioned that it has helped Company C to grow user relationships and diversify its clientele, especially in the infrastructure sector.

These sales team members are tasked with assisting potential users throughout the procurement process by providing detailed information to support material selection. Findings from the three companies revealed that the sales team members provide users with information regarding the different material options and their availability and technical information such as potential applications, best practice construction methods, quality assurance procedures, testing results, and environmental credentials. Furthermore, they proactively monitor the market for upcoming projects and foster and nurture relationships with potential and existing users with the intention of promoting the materials on offer.

According to the company websites, all three companies have established dedicated telephone numbers and email addresses to facilitate direct contact between interested users and the sales team, thereby streamlining the communication process. The findings from Companies A and B specifically revealed that a designated sales team member is assigned to each user, acting as the main point of contact between the company and the user, thus ensuring that the user requirements are fulfilled effectively. The value of this practice was exemplified by a testimonial provided by a Project Engineer involved in the Western Port Highway Upgrade Project, featured on Company B's website. The testimonial highlighted that having a designated point of contact at Company B contributed to the project's smooth operation, even when faced with program and quantity changes.

Notably, the findings from Company B indicated that the sales team members are regularly educated and informed about the materials on offer, enabling them to advise and guide users effectively. For instance, the analysis of Company B's LinkedIn profile unveiled that sales team members are educated about the geotechnical properties of RCAs through site visits to geotechnical laboratories, enabling them to offer users technical insights about using RCAs.

Furthermore, CSA-P3 from Company A and CSB-P3 from Company B mentioned that sales team members are also entrusted with managing user complaints and providing post-sales support where required. CSB-P3 elaborated on this aspect as follows:

> When we do receive like calls or complaints, it's probably from people that haven't used the product before that don't understand its ideal application, and we then obviously work with them to educate them and demonstrate how the product can be used and how it stands up against virgin materials, which they are probably a little bit more used to using.

The findings suggested that personalised marketing through a dedicated sales team could contribute to cultivating stronger user relationships and instilling greater confidence in the materials offered and that such a conversation-based marketing approach is required for marketing RCMs, unlike other commonly used off-the-shelf material solutions.

5.5.1.1.2 Participating in conferences, trade expos, and industry forums

The findings revealed that all three companies participate in conferences, trade expos, and industry forums related to the waste management industry, aiming to market their materials. As mentioned by CSA-P1, CSB-P4, and CSC-P2 from Companies A, B, and C, respectively, such events have been leveraged by the three companies to market their materials in a personalised and interactive manner, directly engaging with large, targeted

audiences through face-to-face interactions. An analysis of the websites of the three companies and the social media profiles of Companies A and B found they are closely affiliated with industry bodies that organise such events such as the Australian Council of Recycling (ACOR), Waste Management and Resource Recovery Association of Australia (WMRR), ecologiQ, and the Infrastructure Sustainability Council of Australia (ISCA). Moreover, the companies have strategically utilised these events by sponsoring them, which has allowed them to enhance their brand awareness among those interested in the waste management and recovery industry. Notably, the findings from Company B revealed that the company's top management has also participated in panel discussions at these events to enhance awareness of their material offerings further. CSB-P6 elaborated on this aspect of Company B's marketing strategy as follows:

> We go to a lot of events, and we make sure we talk about what we do. I mentioned ecologiQ; they held a really great conference last year, and it's us getting out to those events of people who already have a passion for being part of this industry and talking about our products with them. Our MD [name mentioned here was removed for confidentiality reasons] is always doing as much as he can to get the message out there as well.

5.5.1.1.3 Undertaking awareness programs

The findings from Company B highlighted that the company runs its own awareness programs aimed at promoting the environmental and economic benefits of using its materials. One of the key initiatives undertaken by the company in this regard is known as "Green Roads", which is geared towards inspiring the community to adopt better, smarter, and greener ways of road construction by using RCA-based materials. According to CSB-P3, this initiative plays an important role in clearly articulating and demonstrating the value proposition of the company's materials in terms of cost savings and environmental benefits. The interviewee further stated that the company is keen to work with external parties such as local government bodies, community organisations, and other businesses to enhance awareness about the positive and multifaceted benefits of opting for RCMs. This has allowed Company B to market their materials to a broader audience beyond just the end users. However, Companies A and C had not implemented such initiatives, suggesting that they are not seeing much benefit in allocating their resources to physically market their materials to broader generic audiences outside of potential end users.

5.5.1.1.4 Offering opportunities for site visits

CSB-P4 from Company B and CSC-P2 from Company C noted that the two companies offer opportunities for interested users, such as contractors who wish to use RCAs, to visit

their MRFs and witness the DW recovery process firsthand. Herein, CSC-P2 elaborated on the conduct of site visits as follows,

> So, there may be a small minibus with six to twelve people, [and] we'll drive around and show cradle to grave; truck coming in, you'll see him coming in, drop-off material, we'll drive around and come and watch some getting reprocessed and see it coming out the end.

This extract shows that users are given a comprehensive understanding of the complete DW recovery process through the site visits, from receipt of waste materials at the MRF until it is processed and sent to the market. CSC-P2 also mentioned that the company had organised several site visits to its MRF in collaboration with several local councils in South Australia to build broader awareness of its materials.

Furthermore, a review of Company B's LinkedIn profile revealed that the company organises multiple site visits annually, especially in conjunction with conferences and trade expos related to the waste management industry, with the most recent site visit being organised in line with the ecologiQ Greener Infrastructure Conference in 2022 [most recent at the time of data collection]. Both CSB-P4 and CSC-P2 emphasised that observing the conversion of DW into RCAs firsthand instils confidence among users regarding the materials. This assurance stems from the conviction that the materials they receive are not merely a heap of waste but have undergone an organised transformation process. On the contrary, Company A does not encourage site visits, which might be due to safety or security considerations (e.g., the potential for accidents due to the operation of heavy machinery or the possibility of being exposed to hazardous materials) or the need to maintain confidentiality.

5.5.1.2 Electronic channels

Under electronic channels, the findings highlighted that the case study companies had adopted a multitude of measures, including company websites, social media platforms, online newsletters, and external online platforms to market their materials. These measures are explained in detail in the following sections.

5.5.1.2.1 Marketing through company websites

The findings revealed that the three companies had established their corporate websites as primary avenues for marketing their materials to a broader audience. An assessment of these websites demonstrated an extensive array of content designed to aid users in the process of selecting and gaining confidence in using the materials offered by the companies. This included a plethora of information on material grades and compositions,

potential applications, economic and environmental benefits of use, comparable virgin alternatives, quality assurance procedures, environmental credentials, previous successful applications, and current advancements of the companies in the field of waste management. Notably, the websites of the three companies featured several infographic videos about company operations, highlighting the process stages and quality checks that the materials undergo before they are supplied to the market, thereby adding an element of interactivity and making the content more captivating. Furthermore, testimonials from previous project partners, including government bodies, had been included on the website of Company B to bolster market confidence regarding the company's materials.

The websites of Companies B and C also included embedded forms (as shown in Figure 5.7 for Company B) that interested users can use to request online quotes, following which a sales team member would reach out to provide further assistance. This streamlined online communication method has notably simplified the process of reaching out to the company. Interestingly, only Company C disclosed pricing information through its website. Companies A and B had not disclosed pricing information, possibly due to competitive reasons, necessitating users to contact the sales teams for such information.

CSB-P3 and CSB-P5 further noted that Company B plans to integrate an online ordering system with the website to enable users to check real-time stock availability and place orders online, although this has not been implemented yet. With the company website being a key marketing channel, CSC-P2 mentioned that Company C works with online marketers to ensure that it comes up among the top search results when users search the web for RCMs in Adelaide.

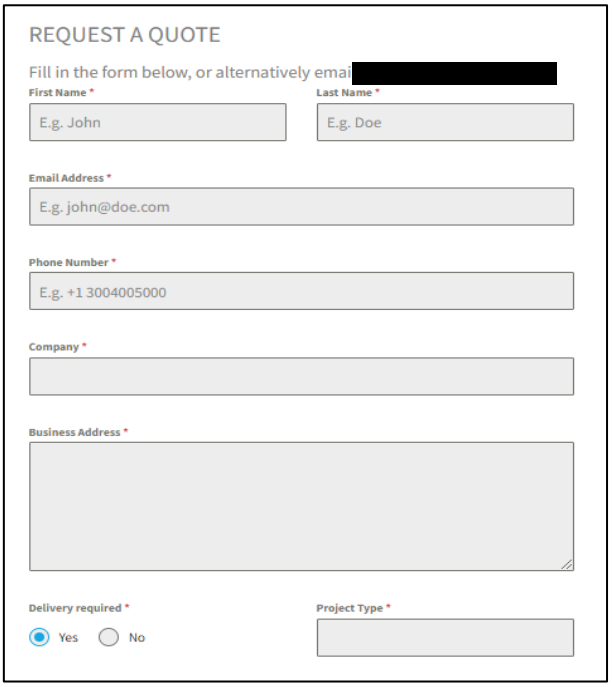


Figure 5.7: Website extract - Option for requesting online quotes – Company B

5.5.1.2.2 Marketing through social media platforms

In response to the growing influence of social media as a marketing tool, Companies A and B have recently established their presence across social media platforms such as LinkedIn, YouTube, and Instagram. Company A has established a strong presence on the professional social media platform LinkedIn, where it regularly posts updates about its materials, successful projects, and other recent developments to capture the attention of CPs who use the platform.

Similarly, Company B has also established its presence across platforms such as LinkedIn, YouTube, and Instagram. As mentioned by CSB-P3 and CSB-P4, the company undertakes extensive content curation in the form of written posts and video infographics, which are then shared across these social media platforms to generate awareness about their materials, their benefits, and successful applications. Interestingly, CSB-P1 noted that LinkedIn has the most significant impact among these platforms, given its professional nature. The use of social media platforms for marketing is evident in Figure 5.8, which shows an excerpt from Company B's LinkedIn profile. As depicted in the figure, the company is seen to be communicating details regarding a past project that had used Company B's materials. Such information on past projects bolsters market confidence regarding the company's material offerings.

Alternatively, Company C is yet to join the others in embracing social media platforms for marketing, possibly due to the relative novelty of using such platforms in the waste recovery industry. In fact, CSC-P2 mentioned that Company C is in the process of improving its social media presence, primarily through LinkedIn.



Figure 5.8: LinkedIn extract - Information on past projects - Company B

5.5.1.2.3 Marketing through online newsletters

As part of their marketing efforts, Companies A and B release quarterly newsletters containing information about past projects, updates on current company activities and news items about the company featured in mainstream media. Access to these newsletters is offered freely to all interested parties, who can opt to subscribe by providing their email addresses through the company websites. According to CSB-P3 from Company B, such newsletters provide a platform for maintaining regular communications with the company's target audience, thus helping to improve brand awareness. Figure 5.9 depicts an extract from the introduction to the newsletter released by Company B in July 2023. As seen through the extract, the newsletter highlights the notable projects the company had undertaken during the specific period. Moreover, the newsletter also draws attention to other significant company achievements, such as obtaining/renewing ISO certifications. This concerted effort augments market awareness about the company's materials while instilling greater user confidence.

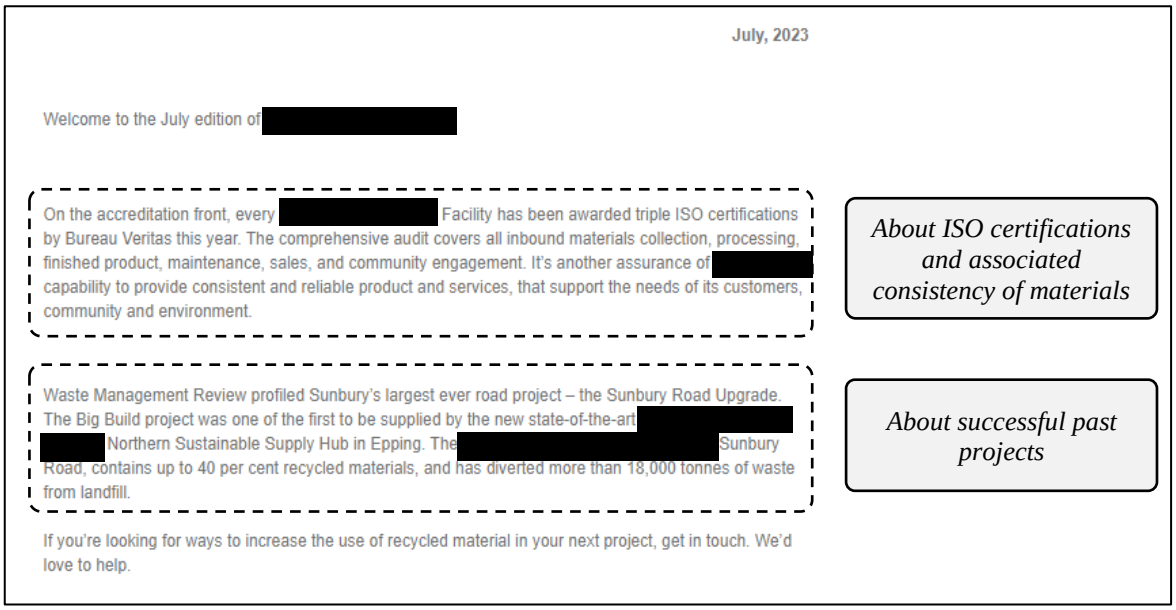


Figure 5.9: Extract from a newsletter - Company B

5.5.1.2.4 Marketing through external online platforms

CSB-P3 mentioned that Company B had posted information about its materials and their sustainability benefits on external platforms, including ecologiQ, Sustainability Victoria, and ISCA. For example, the company is listed on ISCA's "ISupply" database as a preferred supplier for ISCA-rated infrastructure projects. By showcasing its offerings on such external platforms, the company has been able to improve visibility and exposure for its materials within the sustainability-oriented industry community. It is worth mentioning that the absence of similar initiatives by Companies A and C may be attributed to specific requirements, such as registration with organisations like ISCA, in order to post information on such platforms. Furthermore, platforms like ecologiQ and Sustainability Victoria are limited to companies operating within Victoria, which could explain their exclusion by the other two companies operating outside Victoria.

5.5.1.3 Printed channels

Under physical channels, the findings revealed that the case study companies had adopted two measures: developing printed brochures and advertising through trade publications.

5.5.1.3.1 Developing printed brochures

The findings revealed that Companies A and B have developed printed brochures for marketing their materials. Similar to the information on the websites, these brochures include information regarding the materials, such as their potential applications, testing and certifications, benefits of use, previous successful applications, and equivalent virgin alternatives, which enable users to make informed decisions regarding the materials

offered. In Company A, these brochures are also available for download in pdf format through the company website. Figure 5.10 depicts extracts from the brochures from Companies A and B. These extracts indicate that the brochures include information regarding the material grades, intended applications, compliance with specifications, and equivalent virgin alternatives. However, the assertions of CSB-P3 from Company B noted that such printed materials are only used during limited scenarios, such as conferences, and that marketing information is primarily provided in an electronic format in keeping with the company's sustainability ethos. This could also be why such methods are not favoured by Company C.

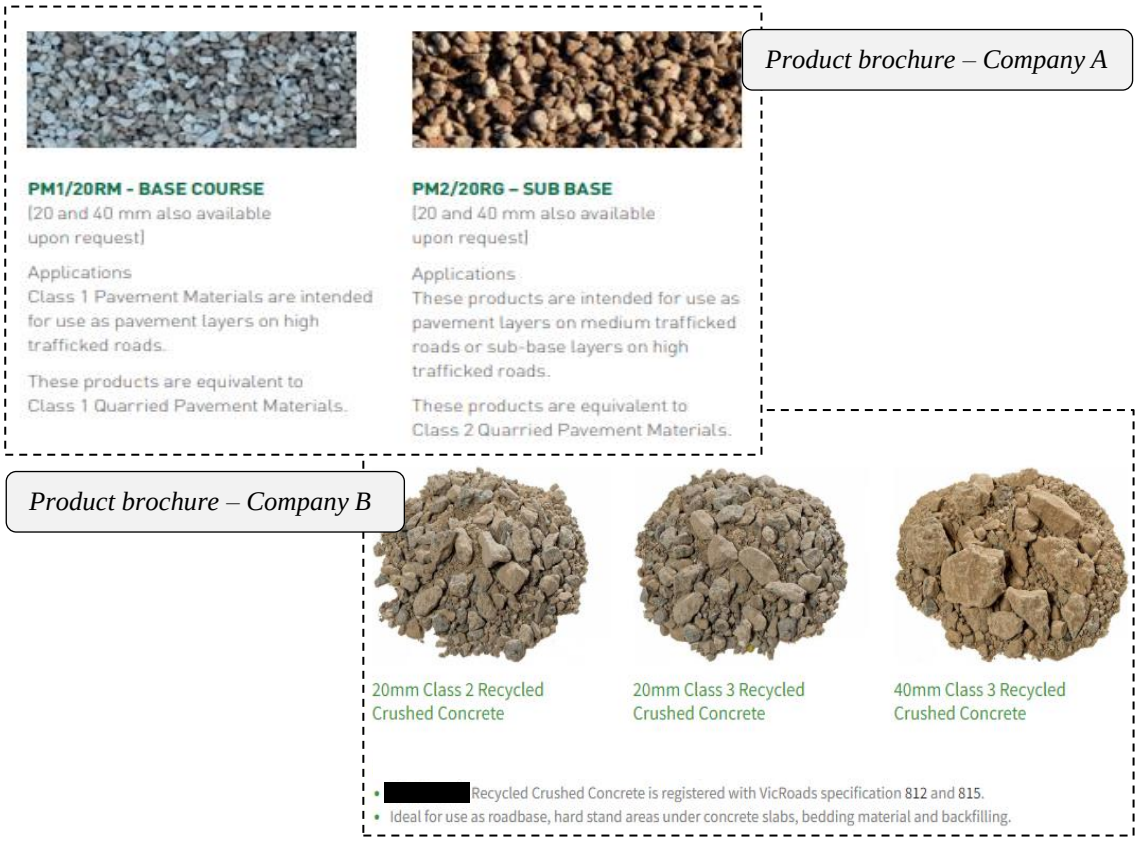


Figure 5.10: Extracts from product brochures - Companies A and B

5.5.1.3.2 Advertising through trade publications

Companies A and B also market their materials through trade publications catering to construction and waste management domains. This aims to raise broader awareness among target audiences, especially those interested in these sectors, thereby bolstering awareness regarding the companies and their material offerings. The content disseminated through these publications includes recent advancements achieved by the respective companies, testimonials from satisfied clients, and insights from past projects highlighting practical applications of the materials in real-life scenarios. For example, both companies have

pursued marketing through the magazine “Waste Management Review”, a magazine dedicated to the waste management sector in Australia.

A summary of the measures taken by the three companies to effectively market their outputs is shown in Table 5.7.

Table 5.7: Summary of measures taken for effective marketing of outputs [CSA- Company A, CSB – Company B, CSC – Company C]

	Measures taken for effective marketing of outputs	CSA	CSB	CSC	Explanation
Physical channels	Establishing dedicated sales teams for one-to-one marketing	✓	✓	✓	Establishing a dedicated team for one-to-one marketing, readily accessible to prospective users through different channels (*e.g., email, telephone*) and capable of addressing all user inquiries, including complaints management and provision of post-sales support
	Participating in conferences, trade expos, and industry forums	✓	✓	✓	Participating in conferences, trade expos and industry forums related to the waste management industry to market materials in a more personalised and interactive manner to large, targeted audiences in a face-to-face setting, whilst also sponsoring such events and participating in panel discussions
	Undertaking awareness programs		✓		Undertaking awareness programs in partnership with government bodies, community organisations, and other businesses to enhance awareness about the positive and multifaceted benefits of using the materials
	Offering opportunities for site visits		✓	✓	Offering opportunities for interested users to visit the material recovery facilities to witness the process of demolition waste recovery firsthand
Electronic Channels	Marketing through company websites	✓	✓	✓	Developing a company website that contains pertinent information about the materials (*e.g., material grades and compositions, potential applications, pricing details, comparable virgin alternatives, quality assurance procedures, environmental credentials, previous successful applications and testimonials, overview of the waste recovery process*) to support material selection, allow the option for making online inquiries, and integrate online ordering systems where feasible
	Marketing through social media platforms	✓	✓		Using social media platforms (*e.g., LinkedIn, YouTube, Instagram*) to post engaging and informative content to make potential users aware of the company and the material offerings
	Marketing through online newsletters	✓	✓		Publishing online newsletters to which interested users can subscribe to obtain company updates

	Measures taken for effective marketing of outputs	CSA	CSB	CSC	Explanation
	Marketing through external online platforms		✓		Posting information about the materials on external online platforms (*e.g., ISupply database of the Infrastructure Sustainability Council Australia*)
Printed Channels	Developing printed brochures	✓	✓		Developing printed brochures that contain information about the materials (*e.g., material composition, potential applications, benefits of use, testing results and certifications, quality assurances procedures, previous successful applications, comparable virgin alternatives*) to support material selection
	Advertising through trade publications	✓	✓		Advertising materials through trade publications specific to the construction and waste management industries

5.5.2 Focus area 2: Measures taken to enhance the cost-competitiveness of the outputs

The findings revealed that to enhance the cost competitiveness of their outputs, the case study companies have focused on managing three cost categories: capital costs, processing costs, and distribution costs, which were recognised as the main cost drivers of the DW recovery process. The measures taken to manage these cost categories are shown in Figure 5.11.

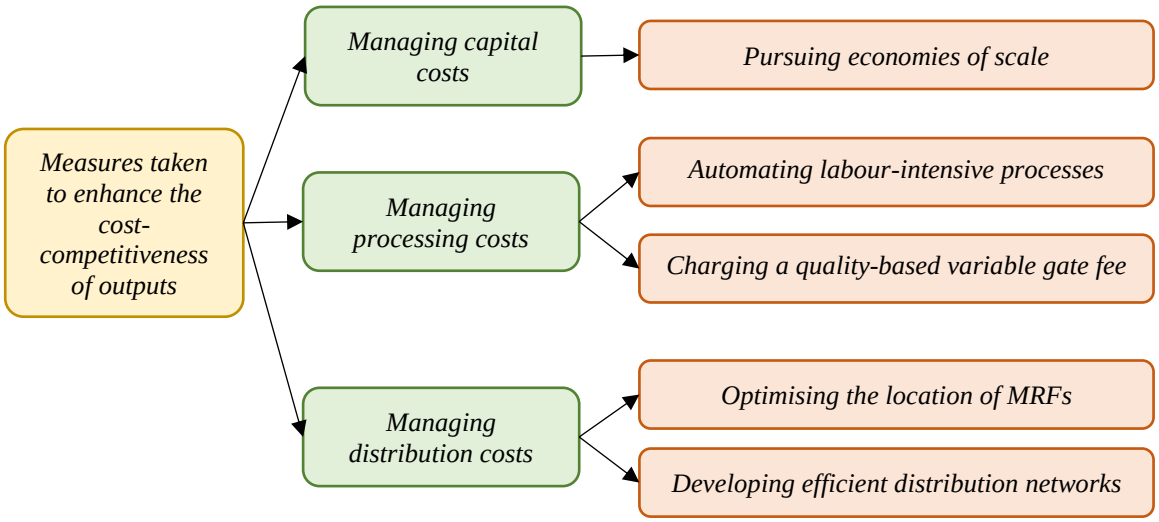


Figure 5.11: Measures taken to enhance cost-competitiveness of outputs

5.5.2.1 Managing capital costs

Pursuing economies of scale was recognised as a key measure undertaken by the case study companies to manage capital costs, which is elaborated in the following section.

5.5.2.1.1 Pursuing economies of scale

CSA-P1 and CSA-P3 from Company A and CSB-P1 from Company B collectively acknowledged the substantial capital investment associated with setting up a MRF. This could include expenses related to securing site space, obtaining required approvals, and procuring specialised plant and equipment. Notably, CSA-P3 highlighted that most specialised plants and equipment for waste recovery must be imported from overseas, primarily from Europe, further escalating the initial capital outlay required for establishing a MRF. This signifies that capital costs are a key cost driver of the DW recovery process and should be managed effectively to provide cost-competitive outputs to the market. As a strategic response to manage the high capital costs, both Company A and Company B have designed their MRFs to achieve high production volumes and operate at optimally high capacities, thereby apportioning the high capital costs across a large output volume. This

approach has effectively reduced the cost per tonne of materials produced, allowing the companies to supply RCAs to the market at comparable prices to their virgin counterparts.

Elaborating on the pursuit of economies of scale in Company A, CSA-P3 remarked, "*Capital investment in the infrastructure, that's a major cost for us…it's capital intensive to start… so scale is always key to manage that*." Likewise, Company B's emphasis on achieving economies of scale is particularly evident through the following comment made by CSB-P1:

> …we are always trying to find ways to reduce our costs. The main one, though, is always scale; the bigger you can make a plant, the more efficient it's going to be…every time we build a new plant, it gets bigger, and if we make adjustments to an existing plant, the crushers and screens will get bigger."

However, CSB-P1 also highlighted that processing capacity must be increased cautiously to match the amount of material that can be sourced for processing and the projected demand for the outputs. The interviewee emphasised that in the absence of sufficient incoming waste materials or market demand for the outputs, economies of scale in processing cannot be realised, and the attempt to do so might result in increased costs, as the company would then need to maintain high levels of redundant capacity. In contrast to Companies A and B, pursuing economies of scale to manage capital costs was not explicitly highlighted in Company C, despite substantial investments made in improving processing capacity.

5.5.2.2 Managing processing costs

The findings revealed that the case study companies had adopted two measures to manage the processing costs: automating labour-intensive processes and charging a variable quality-based gate fee. These measures are explained in detail in the following sections.

5.5.2.2.1 Automating labour-intensive processes

Labour cost was identified as a main driver of processing costs by all three companies due to the labour intensiveness of the DW recovery process. For instance, CSA-P5 from Company A expressed that it takes approximately six full-time employees to produce each tonne of RCAs, whereas a typical quarry of virgin aggregates would require only one or two full-time employees. CSB-P1 from Company B and CSC-P3 from Company C supported this assertion and recognised labour costs as a significant cost driver for both Companies B and C due to the labour-intensiveness of the process of converting DW into RCAs when compared to producing virgin aggregates. As noted by the interviewees from all three companies, this issue has been further exacerbated by the high labour rates

prevalent in Australia. Consequently, all three companies have endeavoured to replace labour-intensive processes with automated processes where feasible.

According to the website of Company A, all the crushing plants are fully automated with specially designed software and require minimum labour input. Some parts of the sorting process are also automated (e.g., magnets for removing metals and air-blowers for removing lightweight materials like plastics). Further, CSA-P3 added that Company A is actively seeking to automate the labour-intensive manual picking stations as well. From the perspective of Company B, CSB-P2 acknowledged that most of the crushing, sorting, and screening plants are automated to a greater extent, requiring minimal human intervention and that it has contributed to increasing the efficiency of the processes. The interviewee added that Company B is exploring potential technological advancements in waste processing to automate its processes further. CSC-P1 also noted that most of the machinery at the MRF of Company C for sorting and processing waste materials are computer controlled with cameras throughout for easy monitoring. The above findings highlight the focus of all three companies in automating their processes to minimise labour involvement and, consequently, the associated processing costs.

However, CSA-P3, CSB-P6, and CSC-P2 from Companies A, B and C, respectively, noted that despite the current technological advancements, specific processes, such as waste sorting, cannot be fully automated due to the heterogeneity of the incoming waste streams, which poses a challenge for machines to sort them efficiently. This is made abundantly clear from the following statement by CSC-P2:

> If you had a full robotic system, I don't think it would work. The problem is there's too many variances in waste…its different sizes, different weights, different densities, different textures. So, a machine isn't going to be able to pick that up…Yeah, there is some automation through there, but it's also going to be a little bit of manual labour as well.

Furthermore, CSA-P1 from Company A noted that the operation of heavy equipment (e.g., excavators, front-end loaders) is also challenging to automate with current technology. The findings, therefore, suggest that effective man-machine combinations could be used to manage labour costs and thereby offer cost-competitive outputs to the market.

5.5.2.2.2 Charging a quality-based variable gate fee

The findings revealed that all three companies charge a variable gate fee from demolition contractors based on the quality of the waste materials delivered to their respective MRFs for processing. In this context, "quality" pertains to the cleanliness or uniformity of the

incoming waste loads, with loads primarily comprising concrete waste categorised as clean, while those mixed with materials like bricks, timber, rubble, and metal are classified as unclean.

This quality-based variable gate fee serves as a revenue stream for the companies to cover the processing costs and maintain competitive pricing for their outputs. Table 5.8 shows the gate fee structure employed by Company A, which was developed based on the gate fee schedule provided by CSA-P3.

Table 5.8: Gate fee details for incoming waste at the material recovery facilities of Company A (as of July 2022)

Waste classification	Wingfield facility		Lonsdale facility	
	Rate/tonne	**+ GST (10%)**	**Rate/tonne**	**+ GST (10%)**
Clean concrete *(predominantly concrete waste)*	$ 45.00	$ 49.50	$ 45.00	$ 49.50
Unclean concrete *(concrete waste mixed with materials like bricks, timber, rubble, and metal)*	$ 55.00	$ 60.50	$ 55.00	$ 60.50

***Note to Table 5.8**: The landfill levy charged in South Australia (where Company A is based) for disposing of similar loads of solid waste in metropolitan Adelaide is $ 149.00/tonne (June 2022 – July 2023). Company A maintains the gate fee for clean and unclean waste loads below this landfill levy*.

As seen from the table, Company A levies a higher gate fee for accepting unclean or mixed waste loads at its MRFs, while a reduced fee is applied for cleaner waste loads. While the precise monetary values of the gate fees were not made available by Companies B and C, insights gathered from the interviewees from these companies (CSB-P2, CSB-P3 and CSB-P5 from Company B / CSC-P3, and CSC-P5 from Company C) affirmed that both the companies charge a similar quality-based variable gate fee from incoming waste loads. The collective findings across the three companies revealed that even if mixed waste requiring more processing is accepted, the corresponding higher gate fee charged allows the companies to offset the additional processing costs incurred, thereby sustaining competitive pricing for their outputs.

5.5.2.3 Managing distribution costs

Alongside managing capital costs and processing costs, the findings underscored the significance of effectively managing distribution costs to ensure the provision of cost-competitive outputs to the market. To manage the distribution costs, the case study companies have optimised the location of their MRFs and have developed efficient distribution networks. These measures are explained in detail in the following sections.

5.5.2.3.1 Optimising the location of MRFs

The findings highlighted that the three companies have optimised the location of their MRFs, locating them in close proximity to metropolitan areas characterised by high construction activity. Furthermore, these locations have been selected based on their easy accessibility via major road networks. Appendices 1(A), 1(B) and 1(C) depict how the three companies have optimised the location of their MRFs. As shown in Appendix 1(A), Company A has two facilities located north and south of the Adelaide CBD. The northern facility is located at Wingfield, which is approximately 17km away from the Adelaide CBD. The location has been selected so that it is closer to the populous northern suburbs of Adelaide and can be accessed easily via major roadways, including the North-South Motorway (marked M2 in Appendix 1(A)) and a system of other arterial roads. Alternatively, the southern facility is located at Lonsdale, which is approximately 26km away from the Adelaide CBD. The facility is also located closer to the southern suburbs of Adelaide and is easily accessible via major roadways. Appendix 1(B) shows the three MRFs of Company B, located in Victoria at Epping, Laverton, and Clarinda. All three sites are located at approximately equal distances from the Melbourne CBD (approximately 20-30km), the capital city of Victoria, and are within the city limits where most of the construction activity takes place. As seen in Appendix 1(B) - Box A, the three facilities are located strategically to cover the major growth areas across Melbourne and are all serviced by a well-developed network of arterial roads and motorways. Similarly, as displayed in Appendix 1(C), the MRF of Company C is located close to the Adelaide CBD (Approx 17km from the Adelaide CBD) and its northern suburbs, where a high volume of construction activity takes place. At the same time, the facility is also accessible via major roadways, including the North-South Motorway (marked M2 in Appendix 1(C)) and a system of other arterial roads.

By optimising the location of MRFs in this manner (i.e., in close proximity to metropolitan areas with easy accessibility via major roadways), the companies have minimised the costs of transporting RCAs from these facilities to construction sites, enabling them to offer RCAs at competitive prices to virgin aggregates that are sourced from quarries located further away from the city limits. Moreover, the findings shed light on the escalating transportation costs linked to using virgin aggregates, as quarries located closer to city limits deplete and move further away. This aspect is highlighted through the following comment made by CSC-P6 from Company C:

> Quarry locations tend to be on the outskirts of metropolitan Adelaide… it's becoming quite expensive to buy virgin materials because their supplies are running low, and transportation costs are going up because you have to drive to quarries around the growing city.

Similarly, CSB-P2 from Company B also noted the movement of quarries for virgin aggregates away from metropolitan regions due to the depletion of resources. Therefore, by having their MRFs closer to metropolitan areas, the companies have taken advantage of this situation to offer RCAs at comparable prices to virgin aggregates through reduced transportation costs.

5.5.2.3.2 Developing efficient distribution networks

The significance of developing efficient distribution networks in effectively managing distribution costs was highlighted through the findings from all three companies. In this regard, the companies have secured access to distribution vehicles of varying capacities, either through company ownership or through third-party contractual agreements, allowing them to fulfil orders of different volumes with minimum truck movements. This, in turn, has yielded savings in distribution costs, thereby enhancing the cost competitiveness of their outputs. According to CSA-P5, distribution activities in Company A are managed through a modern fleet of vehicles, both owned by the company and contracted through qualified and experienced sub-contractors. The company's capability statement confirms its access to a range of licensed and registered distribution vehicles of different capacities, including truck and tri-axle trailers, truck and quad-axle trailers, semi-trailers, B doubles and tandems, 8-wheelers, and 10-wheelers. Similarly, as noted by CSB-P2, Company B also maintains a modern distribution fleet, comprising both company-owned vehicles and tightly managed contracted vehicles. As per the information on the company website, Company B has access to a range of distribution vehicles, including rigid trucks, side tippers, semi-trailers, and various truck-and-dog combinations, each with different capacities. In contrast, CSC-P3 and CSC-P6 highlighted that Company C primarily contracts with third-party logistics service providers for distribution instead of building an extensive internal fleet of distribution vehicles. Nevertheless, this collaboration with third-party logistics service providers has also facilitated Company C's access to a range of distribution vehicles, encompassing small trucks, semi-trailers, and diverse truck-and-dog combinations catering to varying capacities. As explained, the three companies have efficiently managed distribution costs while fulfilling orders of different volumes with fewer truck movements by securing access to distribution vehicles of varying capacities.

Moreover, as per the information on the company websites, Companies A and B have invested in transport management systems that integrate technologies such as GPS. These systems have allowed the companies to conduct real-time monitoring of vehicle movements and create efficient schedules for their transportation operations. By leveraging these technologies to optimise vehicle scheduling, Companies A and B have successfully reduced their distribution costs.

A summary of the measures taken by the three companies to enhance the cost-competitiveness of their outputs is presented in Table 5.9.

Table 5.9: Summary of measures taken to enhance the cost-competitiveness of outputs [CSA- Company A, CSB – Company B, CSC – Company C]

Measures taken to enhance the cost-competitiveness of outputs			CSA	CSB	CSC	Explanation
	Measure	Sub measures				
Managing capital costs	Pursuing economies of scale	-	✓	✓		Designing material recovery facilities to operate at optimally high capacities to apportion fixed capital costs across a larger output volume, thereby effectively reducing cost per unit
Managing processing costs	Automating labour-intensive processes	-	✓	✓	✓	Minimising the labour involvement and associated labour costs by automating processes where feasible
	Charging a quality-based variable gate fee	-	✓	✓	✓	Charging a variable gate fee based on the quality of the incoming waste materials (*i.e., a higher gate fee for unclean waste loads and a lower gate fee for clean loads*) to reduce/recoup processing costs
Managing distribution costs	Optimising the location of MRFs	-	✓	✓	✓	Optimising the location of material recovery facilities to minimise the cost of transporting processed materials from these facilities to construction sites
	Developing efficient distribution networks	Access to distribution vehicles of different capacities	✓	✓	✓	Establishing access to distribution vehicles of different capacities, which can be used to fulfil orders of different volumes with minimum truck movements
		Transport management systems incorporating technologies such as GPS for optimising vehicle scheduling	✓	✓		Using transport management systems that incorporate technologies such as GPS for optimising vehicle scheduling

5.5.3 Focus area 3: Measures taken to assure the quality of the outputs

The findings highlighted that to assure the quality of their outputs, case study companies have focused on ensuring input quality of incoming waste, minimising quality failures in processing, and resolving post-sales quality issues. Further, product research was recognised as another avenue identified under a separate category as "other" measures. The measures taken by the case study companies to assure the quality of their outputs are shown in Figure 5.12.

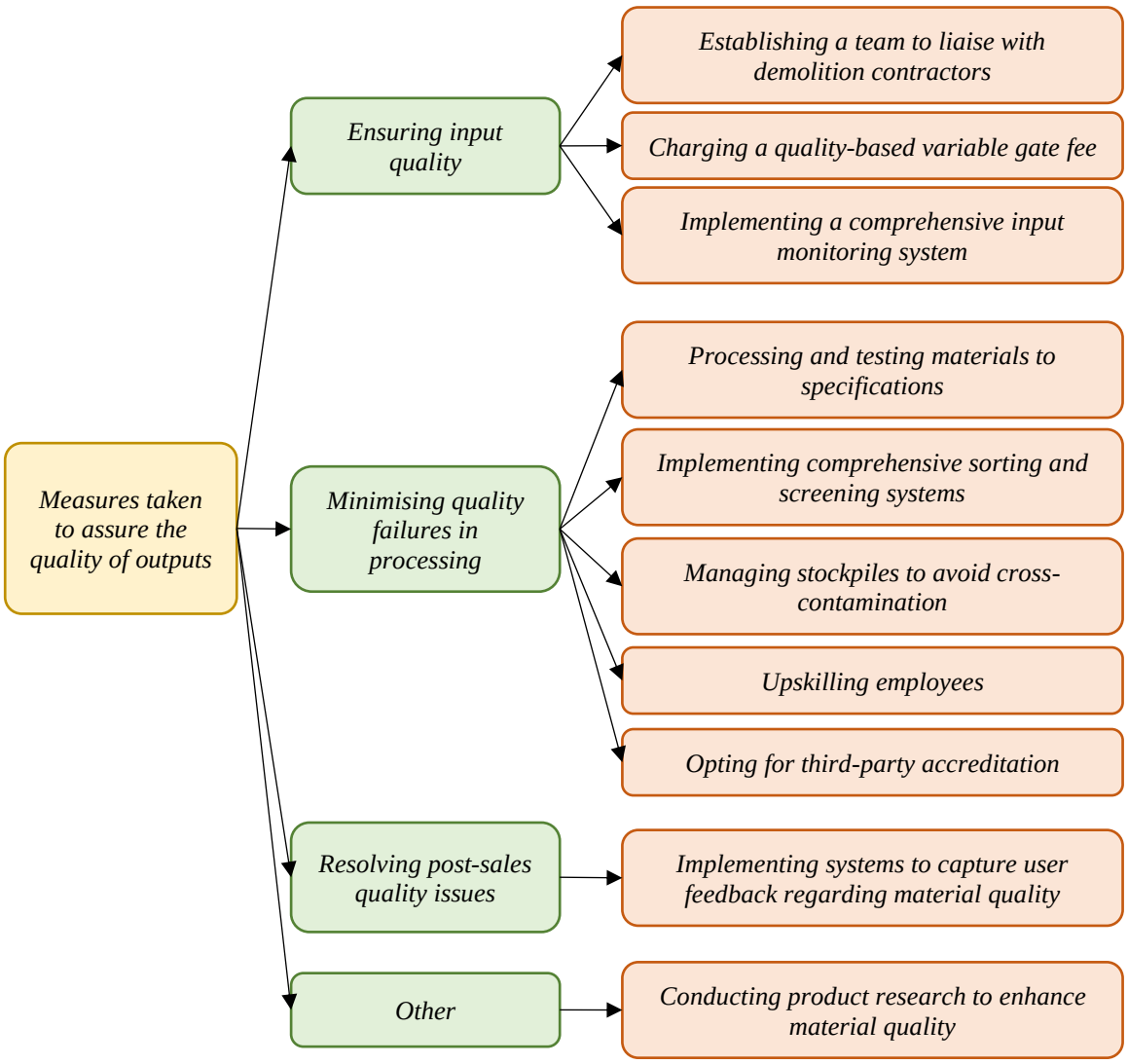


Figure 5.12: Measures taken to assure the quality of outputs

5.5.3.1 Ensuring input quality

The findings underscored the significance of maintaining the quality of incoming waste as a crucial determinant in producing outputs of superior quality. Consequently, the study delineated three specific measures that were adopted by all three case study companies to ensure the quality of the inputs. These include establishing a team to liaise with demolition

contractors, charging a quality-based variable gate fee and implementing a comprehensive input monitoring system. These measures are explained in detail in the following sections.

5.5.3.1.1 Establishing a team to liaise with demolition contractors

The findings revealed that all three companies have established dedicated teams to liaise with demolition contractors. As noted by CSA-P3, CSB-P3, and CSC-P1 from Companies A, B and C, respectively, these teams across all three companies play a pivotal role in educating demolition contractors about the waste acceptance criteria and the undesirable materials that must be avoided when delivering waste materials to their MRFs. This proactive engagement with demolition contractors has facilitated the receipt of cleaner waste streams, pre-sorted to meet the waste acceptance criteria of the MRFs and devoid of undesirable materials like asbestos, thus enabling the production of high-quality outputs. The importance of such educational efforts was effectively highlighted through the following statement made by CSB-P3:

> …it's about educating people, you know, in demolition, people that are wanting to recycle waste, about what waste is recyclable and what waste is acceptable. I think as long as you can do that, and then you've got good systems and processes on-site and good risk management on-site, then you can be pretty much assured that you are going to be delivering a quality product to the customer.

Additionally, in Company C, upon request from demolition contractors, the team conducts site visits to inspect waste stockpiles and evaluate the quality of the waste materials. As expressed by CSC-P5:

> If they [demolition contractors] have questions about the grade of materials they are tipping, we are happy to visit the site and look at the stockpiles and give an estimate of the grade we think it might be.

According to the interviewee, this approach serves a dual purpose; not only does it support demolition contractors to make informed decisions regarding potential disposition options, but it also allows Company C to evaluate the suitability of the waste materials for reprocessing, thereby effectively positioning the company to source waste materials that can be processed into high-quality outputs.

5.5.3.1.2 Charging a quality-based variable gate fee

The study findings highlighted the shared practice among all three companies in employing the gate fee to regulate the quality of incoming waste materials. This is achieved by altering the gate fee based on the characteristics of the waste received. A higher gate fee is charged if the incoming waste loads are heavily contaminated with undesirable materials,

whereas a lower gate fee is charged if it is comparatively cleaner. As expressed by CSC-P3 from Company C, the gate fee is used here as a mechanism to stimulate the receipt of cleaner waste streams:

> You use price as a mechanism to encourage a cleaner product…you just have a look at the loads and charge accordingly…more money if it's dirty and less money if it's clean [CSC-P3].

The operationalisation of this variable gate fee based on the quality of incoming waste is made clear in Table 5.8 (refer to Section 5.5.2.2.2), which presents the gate fee structure employed by Company A. As shown in the table, a higher gate fee is levied by Company A for accepting unclean or mixed waste loads. In contrast, a reduced gate fee is applied for cleaner waste loads.

The imposition of a higher gate fee for mixed or unclean waste loads has incentivised demolition contractors to pre-sort waste materials before delivering them to the MRFs. CSA-P2 from Company A expanded upon this aspect as follows:

> They've [demolition contractors] got good at separating the waste coz [because] they understand that clean concrete is cheaper to dispose of than mixed or unclean. So, on the site, they'll dig out all the clean concrete coz then, that'll get them a better rate, whereas if they just bring us truckloads of mixed rubbish, it'll cost them more.

This use of the gate fee to encourage pre-sorting of waste materials was further exemplified in the following statement made by CSB-P5 from Company B: "*They are* [waste materials] *meant to come sorted…so, yeah, there's varying pricing depending on the material to encourage that split*." These findings acknowledge that charging a quality-based variable gate fee encourages demolition contractors to pre-sort waste materials before delivering them to MRFs, which in turn has enabled the MRFs to receive cleaner waste streams that can be used to produce higher-quality outputs.

5.5.3.1.3 Implementing a comprehensive input monitoring system

The findings highlighted that all three companies have implemented comprehensive multi-stage systems for monitoring waste loads prior to their acceptance for processing at the MRFs. Insights gathered from the interviewees of the three companies, alongside infographic videos on company websites and videos on the social media platforms of Companies A and B, unveiled that the three companies have adopted similar systems to oversee the quality of incoming waste materials. These systems predominantly involve two monitoring stages.

As the first stage of the monitoring system, all incoming waste loads are checked on the weighbridge at the point of entry to the MRFs. Trained weighbridge operators inspect each truckload of waste that enters the MRFs using a combination of elevated platforms and camera systems to ascertain the suitability of the materials for processing. If the weighbridge operators identify any loads heavily contaminated with undesirable materials, they will not be accepted for processing. Herein, special attention is placed on verifying the presence of hazardous materials like asbestos, which the facilities are not licensed to accept and can pose a serious threat to the output quality. The significance of monitoring for asbestos was particularly emphasised by CSB-P2 and CSB-P3, who highlighted that Company B has a strict policy of not accepting materials that might even look like asbestos; *"Asbestos is probably the one that we look out for the most, and we don't even accept materials that look similar because obviously, that could cause problems for the customer"*, said CSB-P3. Alternatively, if the weighbridge operators determine that a specific load is suitable for processing, it will be forwarded to the tipping area, also known as the tip head.

As the second stage of the monitoring system, specialised teams of trained employees – referred to as "spotters" in Companies A and C and "load inspectors" in Company B - examine the waste loads as they are unloaded at the tipping area. This step is designed to detect any undesirable materials that might be present at the bottom of the truckloads of waste, which might have gone unnoticed during the initial inspection at the weighbridge. Interviewees from all three companies (CSA-P2 from Company A / CSB-P2 and CSB-P3 from Company B / CSC-P2 from Company C) highlighted that certain rogue demolition contractors might deliberately conceal undesirable materials, such as asbestos, at the bottom of truckloads to evade detection at the weighbridge. CSA-P2 provided insights into this issue as follows:

> So, over the years, there's been the odd issue around contaminated loads, you know, there's… some operators, some demolition contractors aren't the most trustworthy people. So, they might, you know, we've had instances where people might put asbestos on the bottom of their truck and then fill it up with concrete and bricks, so when it comes over the weighbridge, we can't see it.

The spotters or load inspectors stationed at the tipping area can capture such malpractices. Should undesirable materials be observed, the corresponding loads are rejected and subsequently reloaded to be sent back. If any hazardous materials are identified, such loads will be handled with precaution per the regulatory requirements for handling asbestos-containing materials. Alternatively, loads deemed suitable for processing are directed to

designated stockpiles for further processing. If a particular demolition contractor consistently delivers poor-quality materials unsuitable for processing, they would initially be given a warning. However, if the issue persists, the companies cease accepting waste loads from such demolition contractors. To ensure that waste loads from rogue demolition contractors are subjected to thorough examination in the future, a detailed record of all rejected loads is maintained in a designated rejected loads register. This two-staged monitoring system commonly followed by the three companies is depicted in Figure 5.13.

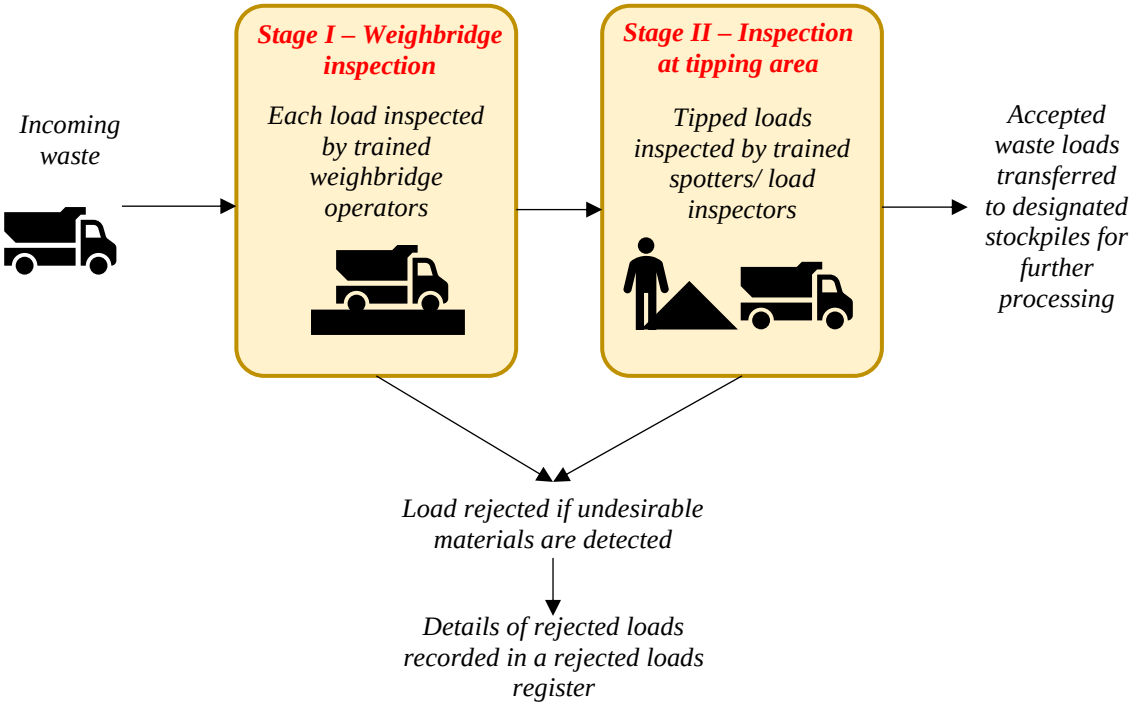


Figure 5.13: Input monitoring system adopted by companies

5.5.3.2 Minimising quality failures in processing

Following ensuring input quality, the findings highlighted the significance of waste processors focusing their attention on minimising quality failure in processing. The study identified five measures that the case study companies had implemented to minimise quality failures in processing, including processing and testing materials to specifications, implementing comprehensive sorting and screening systems, managing stockpiles to avoid cross-contamination, upskilling employees, and opting for third-party accreditation. These measures are explained in detail in the following sections.

5.5.3.2.1 Processing and testing materials to specifications

According to the study findings, all three companies have set up their processes to ensure that the materials they produce conform to industry specifications. Herein, Companies A

and C, operating within South Australia, produce their concrete aggregates and pavement materials to meet the specifications of DIT South Australia and drainage aggregates to meet the specifications of SA Water (The public body responsible for managing water and sewage services in South Australia). CSA-P2 elaborated on the compliance of Company A's pavement materials with DIT specifications as follows:

> So, we manufacture everything to the DIT specification, which is the Department for Infrastructure and Transport. So, they are responsible for the specifications around road construction in South Australia…So, they put out… they've got a pavement team, and they've put out a specification…So, all of our products meet that specification, so we manufacture to that."

Similarly, CSC-P2 affirmed that Company C's core products intended to be used in road base applications, such as PM2/20, are produced to meet DIT South Australia specifications, while screened aggregates, which can be used as pipe bedding materials, are produced to meet SA Water specifications. A review of the websites of Companies A and C also showed that the companies produce their outputs to meet the relevant industry specifications (refer to Figure 5.14 for website extracts). In a similar vein, CSB-P5 noted that Company B, based in Victoria, produces its pavement materials according to the VicRoads (Department of Transport and Planning from 1st January 2023) specifications, which is the main governing body responsible for overseeing road infrastructure projects at the state level. This was affirmed by a review of the website of Company B (refer to Figure 5.14 for website extracts). The findings from the three companies revealed that the waste recovery process is controlled to obtain output materials of different grades, as set out in the specifications. For example, clean concrete is fed into the waste recovery plant with required quality controls to obtain pavement materials specified as Class 1, while concrete mixed with small amounts of brick is fed to obtain pavement materials specified as Class 2.

Further, interviewees from all three companies (CSA-P3 and CSA-P5 from Company A / CSB-P1 and CSB-P2 from Company B / CSC-P1, CSC-P2 and CSC-P3 from Company C) stated that the materials produced are tested periodically as per the testing regimes stipulated in the relevant specifications, following Australian standard test methods, through NATA-accredited laboratories. While Companies A and C rely on external laboratories for testing, Company B has developed its own in-house testing facilities, which is justifiable considering the higher volume of materials handled by Company B annually. A review of company documents of the three companies showed that various tests are carried out to assess the physical and chemical characteristics of the materials, including particle size distribution, liquid limit, plasticity index, linear shrinkage, Los

Angeles abrasion, and foreign material content. Special attention has also been given to asbestos testing since it is considered a hazardous material, where inhaling asbestos fibres can have severe health implications. A generic set of outcomes of these tests is made available through the websites of the three companies. Moreover, all three companies have provided users the opportunity to request additional testing for specific batches of materials if required. The findings revealed that regular testing allows the companies to identify and rectify process issues, thereby reducing the likelihood of sending sub-standard materials to the market.

Interestingly, details regarding completed projects on the websites of Companies A and B showed that the two companies could also develop unique material blends tailored to the requirements of specific projects. An example is the Mordialloc Freeway, for which Company B developed high-quality road base material specifically for the project to meet improved sustainability outcomes expected from the project. Additionally, Companies A and B have obtained pre-qualification or accreditation from governmental bodies for some of their RCA-based outputs, thus further driving user confidence regarding the quality of their materials. Herein, the website and quality assurance documents of Company A revealed that the 20mm Class 1 pavement materials produced by the company have been prequalified for use in DIT projects, following comprehensive testing by DIT and other independent NATA-accredited laboratories (refer Figure 5.14 for website extract). Likewise, the analysis of Company B's website showed that following comprehensive testing, some of the RCA-based outputs of the company (primarily those used as roadbase) are accredited by government bodies, such as Sustainability Victoria and VicRoads (refer Figure 5.14 for website extract). However, such measures were not evident in Company C, possibly due to resource constraints such as a lack of in-house expertise to develop tailor-made outputs and the generally lengthy and costly government pre-qualification/accreditation processes.

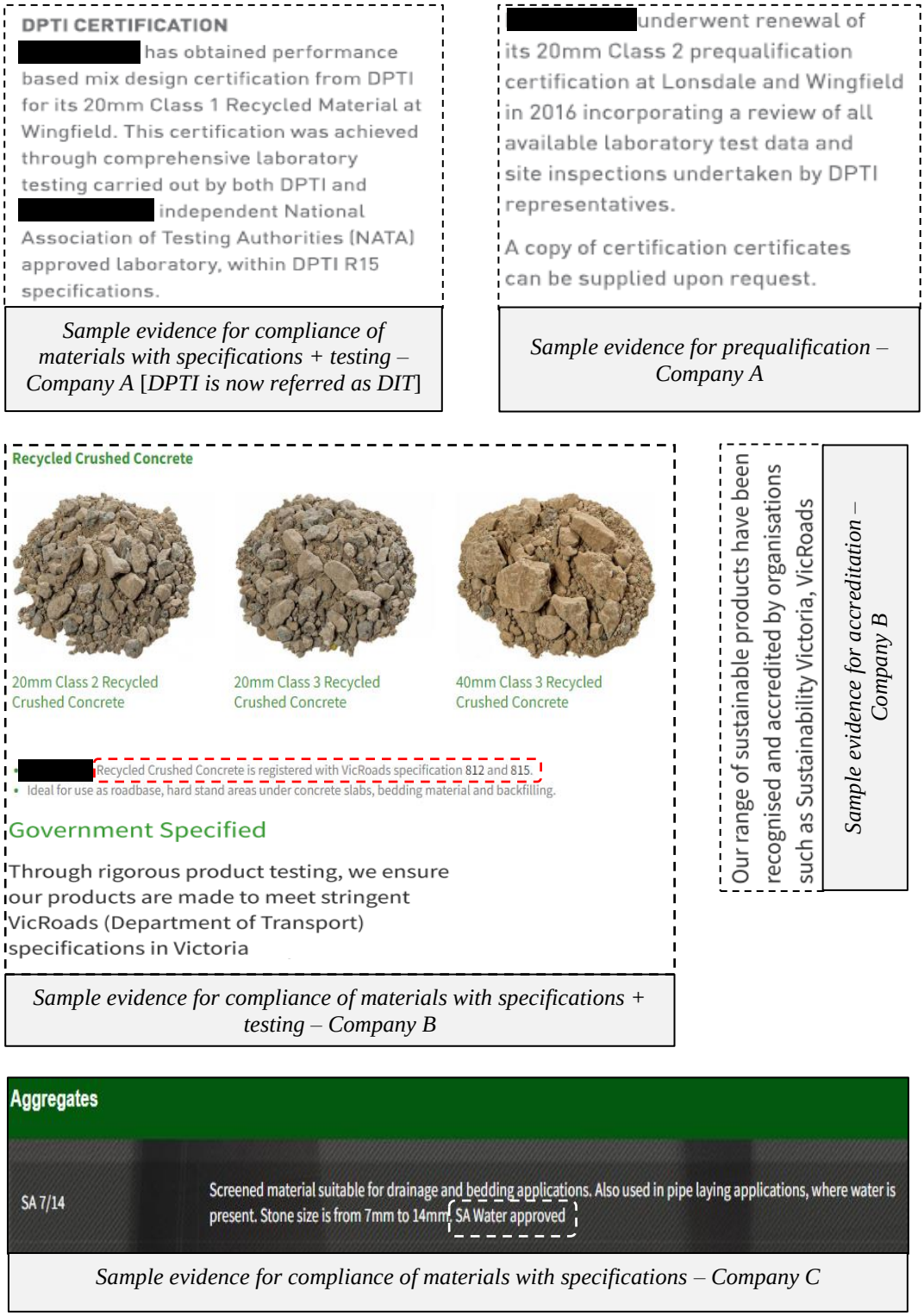


Figure 5.14: Website extracts - Sample evidence for compliance of materials with specifications - Companies A, B and C

5.5.3.2.2 Implementing comprehensive sorting and screening systems

Despite waste loads being inspected upon receipt at the MRFs, certain undesirable materials could pass through to subsequent processing stages. Therefore, all three companies have implemented comprehensive material sorting and screening systems to

remove such materials which can affect the quality of their outputs. These systems employ a combination of automated and manual methods, such as magnetic separators for metals, air blowers and water baths for lightweight components (e.g., timber, plastic, paper), computer-controlled crushers for monitoring input quality, manual picking stations for enhanced detection, and mechanical screens for size grading. Since the systems adopted by the three companies showed several variations, they are explained separately in detail as follows:

Company A: As shown in Figure 5.3 (refer to Section 5.4.1.2), waste materials accepted at the MRFs initially undergo primary crushing (large concrete elements like footings and slabs are pulverised before primary crushing), following which the undesirable materials are sorted and removed from the waste stream. A range of manual and automated methods are used to sort the waste. A system of magnets separates the metals, and these salvaged metals are then transported to specialist third-party metal recyclers for further sorting and recycling. Air blowers are used to remove lightweight materials like timber fragments, paper, and plastics. The waste stream is also passed along a conveyor through a picking station, where the remaining undesirable materials are removed manually by waste pickers. The separated combustible materials (e.g., timber fragments, plastics) are sent to the company's sister plant, which converts this waste into a high-energy fuel used in cement kilns. Any unrecoverable materials generated as a result of the sorting process are disposed of at a licensed landfill operated by the company. The clean concrete waste derived following this sorting process is then passed through a series of screens to produce RCAs of specific sizes and crushed further if required.

Company B: As shown in Figure 5.4 (refer to Section 5.4.2.2), manual and automated methods are used to sort the waste materials following the primary crushing stage. Herein, over-band magnets and eddy current magnets are used to remove ferrous and non-ferrous metals (e.g., reinforcement in concrete waste) from the waste stream, which is then collected and transported to specialist third-party metal recyclers for recycling. Next, the materials pass along a conveyor belt through an enclosed picking station, where several waste pickers remove materials such as timber and plastics from the waste stream, which are disposed of at licensed landfills. The clean concrete waste derived following this sorting process is then sent for screening and secondary crushing. A system of screens is used to separate

the resultant materials into RCAs of different sizes, and secondary crushing is carried out to further grade the RCAs into smaller sizes as required.

Company C: As shown in Figure 5.5 (refer to Section 5.4.3.2), waste pickers initially remove the lightweight undesirable materials (e.g., small pieces of plastics, timber, metals) that can be removed easily, and an excavator with a grab is used to remove larger fragments (e.g., larger timber sections). Before further sorting, the materials undergo primary crushing and screening to remove fine materials like soils, which are processed separately. After that, a range of automated and manual sorting techniques are used to remove any undesirables from the remaining waste fraction. All the materials are passed under an elevated magnetic conveyor belt, thereby automatically removing all ferrous elements. Then, eddy current magnets are used to remove non-ferrous metals like aluminium from the waste stream. Next, the materials go through a water bath for density separation where "heavies", such as concrete and brick, sink and are separated from "lights", such as timber and plastics. Following this, the materials pass through an enclosed picking station, which houses a team of waste pickers who sort the materials manually before the inert material fraction is sent for secondary crushing and screening to be converted into RCAs of different sizes. Interestingly, CSC-P3 mentioned that the design of the picking station was developed internally within the company to maximise the sorting efficiency and that the company has subsequently acquired a patent for the design. CSC-P1 also noted that the crushers are computer-controlled to monitor the input, and cameras are installed throughout to closely monitor the sorting and screening processes.

An important point of consideration is the incorporation of manual picking stations as part of the sorting process since machines might be unable to capture all undesirable materials effectively due to the high variation observed in incoming waste streams. Adopting robust sorting and screening systems, as explained above, has ensured that the materials produced by the three companies are devoid of undesirable materials, thus minimising quality failures with the outputs.

5.5.3.2.3 Managing stockpiles to avoid cross-contamination

Stockpile management was recognised as another step taken by the companies in their efforts to minimise quality failures in processing. All three companies have implemented a system of separate stockpiles for different categories of incoming waste and processed

materials to prevent cross-contamination. This involved maintaining separate stockpiles for clean and mixed waste designated for processing, as well as the different grades of materials produced.

In the case of Company A, CSA-P2 elaborated on how the stockpiles for incoming waste materials are managed as follows:

> So, if someone comes over the weighbridge and they've got a load of clean concrete, and the guys on the weighbridge have a look at it and say yes, that is clean, there'll be an area up on our pad where they tip clean concrete and there's an area for unclean concrete. So, when we go to make the relevant material, we know to get the clean concrete from here to make Class One and the unclean concrete from here to make Class Two.

The interviewee further mentioned that once the waste materials are tipped at the designated stockpiles, the potential for contamination is less since concrete waste is heavy and does not get blown about, unlike low-weight materials. Like the incoming waste materials, CSA-P6 stated that processed materials are also stockpiled in separate bays to avoid mixing materials of different grades and sizes.

A similar approach to managing stockpiles of incoming waste was followed by Company B, as evidenced by the following extract from the interview with CSB-P2:

> We separate the concrete and other materials…so let's say someone was to bring concrete, so we separate…concrete in one section, and then there would be what we would call a mixed area, which is generally brick and some concrete…just making sure they are separate.

Adding to this, CSB-P1 mentioned that processed RCAs, especially those intended for use in concreting applications, are stored separately, considering their lower threshold for foreign materials compared to those used in road base applications. Further, CSB-P6 noted that a signage system has been implemented to indicate the positions of distinct material stockpiles on site.

In parallel to Companies A and B, Company C has also adopted a similar well-organised approach for stockpile management, wherein the interview with CSC-P1 affirmed that separate stockpiles for clean and mixed concrete waste and processed materials are maintained in designated areas within the processing facility to avoid possible cross-contamination.

Interestingly, CSB-P6 mentioned that in Company B, aerial photographs are also captured using drones to establish the locations of the different stockpiles accurately and that this information is communicated to on-site employees to help them identify the specific

stockpiles effectively. Moreover, CSA-P3, CSB-P3, and CSC-P1 from Companies A, B and C, respectively, noted that the companies had established protocols for handling hazardous materials like asbestos if identified within the stockpiles. This organised approach to stockpile management followed by the three companies has ensured that materials, both pre- and post-processing, are consistently stored in their designated stockpiles, thereby preventing cross-contamination during site operations.

5.5.3.2.4 Upskilling employees

As gleaned through the analysis of Company A's capability statement, a skilled workforce has played a pivotal role in building the company's market reputation as a supplier of high-quality materials. Reflecting Company B's perspective, CSB-P3 expressed that the DW recovery process requires skilled labour for activities such as input control, operating machinery, waste sorting, and process supervision, and unless these employees are skilled in their respective tasks, the quality of the output can be affected negatively. Following a similar line of thought, CSC-P1 from Company C mentioned that the company's success hinges on its employees and that investing in upskilling them is crucial for delivering high-quality outputs to the market.

Recognising this pivotal role of skilled labour in producing high-quality outputs, the three companies have implemented internal training and capacity-building programs to upskill their employees. Synthesising the findings across the three companies revealed that targeted training and capacity-building programs have been implemented for different categories of employees engaged at various stages throughout the DW recovery process, whom all have a part to play in ensuring that the outputs produced consistently meet the expected quality standards. For instance, employees stationed at the weighbridge, who oversees the inflow of waste materials, receive continuous education regarding acceptable waste materials, tolerance thresholds for undesirable substances, and detecting anomalies within waste loads. The spotters or load inspectors, responsible for examining incoming waste materials as they are unloaded from trucks, undergo training to identify hazardous materials (e.g., asbestos) and other contaminants. Waste pickers are trained to recognise undesirable materials and to segregate them into separate fractions for further processing. Machine operators are also equipped with the knowledge and skills needed to configure machines for processing various waste streams to achieve the desired output quality.

Notably, in light of the current scarcity of skilled labour in Australia, all three companies have intensified their efforts to upskill their internal workforce. Herein, CSA-P2 mentioned

that Company A has started to provide training opportunities for entry-level employees to assume more skilled roles. Similarly, CSB-P3 mentioned that in recognising the shortage of skilled labour in Australia, Company B has recently implemented new training and development programs to recruit individuals without prior experience, equipping them with the skills and experience needed to maintain its operations at an optimum level. Company C has taken a parallel approach, where CSC-P3 highlighted that, given the existing shortage of skilled labour, Company C has increasingly relied on internal training to cultivate its skilled labour pool.

5.5.3.2.5 Opting for third-party accreditation

According to the study findings, all three companies had successfully obtained ISO 9001 - Quality Management Systems certification for their quality management processes. This certification advocates for a process-based approach to quality management, emphasising the importance of understanding and meeting customer expectations, establishing quality objectives, and utilising these objectives to drive continuous process improvement. Consequently, by opting for this third-party certification, the three companies have continuously improved their quality management processes, thereby ensuring the consistency and reliability of the quality of their outputs.

As per the findings from Company A, both its MRFs hold ISO 9001 certification and all stages of the DW recovery process are carried out in accordance with the requirements outlined in this certification. CSA-P4, the Health, Safety, Environment, and Quality (HSEQ) Manager, is responsible for administering the quality management processes within the company. CSA-P4 stated that the ISO 9001 certification considers all things quality-related and covers three main aspects: (1) operational controls – the nature of quality inspections the company has, (2) document controls – the quality policies and procedural documents developed by the company and (3) product quality – how the company manages product quality in terms of testing, maintaining records, and addressing customer feedback. The company undergoes annual surveillance audits through certification bodies to assess compliance with the certification scheme, during which non-conformities and opportunities for improvement are identified. These non-conformities and opportunities for improvement are subsequently passed onto responsible parties for action, and corrective actions are taken before the next audit cycle, fostering an atmosphere of continual quality enhancement within company processes. CSA-P5 also mentioned that the processing facilities are subject to monthly audits conducted by the internal quality team,

led by the HSEQ Manager, as part of the company's commitment to the ISO 9001 certification.

Similar to Company A, all three of Company B's MRFs also hold ISO 9001 certification. According to the company's website, it has consistently maintained its ISO 9001 certification for over a decade, from 2012. In Company B, CSB-P5, the Sustainable Products Technical Manager oversees the quality management processes and ensures compliance with the ISO certifications. As explained by CSB-P5, the interviewee is assisted by a team comprising members from different MRFs who ensure that effective quality controls are consistently applied and that records of all quality-related activities are maintained in line with the certification requirements. Furthermore, the interviewee affirmed that measurable quality objectives are established and periodically reviewed through surveillance audits to ensure that the materials offered continue to meet user expectations, aligning with the requirement for continuous improvement advocated by the ISO certification.

Like the other two companies, the MRF of Company C is also ISO 9001 certified, demonstrating the company's ability to consistently provide quality outputs that meet user requirements. CSC-P2 mentioned that a quality management officer is employed full-time to ensure that the company meets the standards required for maintaining the ISO certification. The interviewee noted that third-party certification has helped the company develop its internal policies and procedures to improve the quality of its outputs. As expressed by CSC-P1, the annual surveillance audits conducted under the certification scheme have enabled the company to identify areas for improvement and continuously refine its quality management system, thereby providing quality outputs to the market.

Furthermore, Company B has specifically ensured that all its onsite testing laboratories are accredited by NATA, which assures users of the reliability and accuracy of the company’s test results.

5.5.3.3 Resolving post-sales quality issues

Recognising the potential for quality concerns emerging after the sale of their materials, the case study companies have acknowledged the significance of implementing measures to identify and address post-sales quality issues. To address this aspect, the companies have implemented systems to capture user feedback regarding the quality of their materials so that it could be used to improve their processes. This measure is explained in detail in the following section.

5.5.3.3.1 Implementing systems to capture user feedback regarding material quality

As noted by CSA-P4, Company A has implemented a feedback management system to capture user feedback regarding the quality of its materials. If any negative feedback is captured, it is recognised as an opportunity for improvement and a non-conformance report is raised. This report is then uploaded onto an internal organisational information management system and disseminated across the company for the issue to be actioned by responsible parties. This system has enabled the company to identify quality issues with its materials and take corrective actions to improve its processes to prevent such issues from recurring. Interestingly, CSA-P2 and CSA-P3 highlighted several instances where the company had improved its processes in response to quality issues raised by users. The following extract from the interview with CSA-P3 notes such an example:

> Recently, we had an example where some small bits of metal, aluminium, I think it was, got into the product. The team or the contractor who took the product observed it; our guys went straight out there, called the relevant areas, fixed the material, and kept that relationship going…we've fought so hard to get people on board to take this product; we really take it seriously when it doesn't work."

CSB-P1 and CSB-P2 noted that Company B has also developed a sophisticated process for addressing negative feedback regarding the quality of its materials. According to the interviewees, when a user raises a quality issue, it is initially logged into a complaints management system for further investigation. Following this, the company proactively investigates the source of the problem, and once this is identified, appropriate remedial actions are taken to address the underlying problem at its source.

While not as sophisticated as the processes employed by Companies A and B, Company C, through its team of sales executives, also gathers user feedback regarding the quality of its materials. When shortfalls in quality are identified, the company actively collaborates with users to resolve these issues while simultaneously leveraging the insights gained to improve its processes in the long run. CSC-P3 elaborated on this point as follows:

> From time to time, there can be the odd quality issue… our products are generally pretty clean, so it's not too bad. But of course, there can sometimes be issues. If that happens, we talk to the customer, and then know what happened and in the first instance, provide a solution to the customer, and then in the long run, try and improve any process shortcomings that led to the problem in the first place.

Implementing these feedback systems has allowed the three companies to dissect their processes, identify shortcomings, and take necessary action to rectify them, thereby eliminating recurring quality issues and enhancing the overall quality of their outputs.

5.5.3.4 Other measures

In addition to the aforementioned measures, undertaking product research was recognised as an overarching measure to enhance material quality, as explained in the following section.

5.5.3.4.1 Conducting product research to enhance material quality

Companies A and B, in particular, have identified product research as an overarching strategy for assuring the quality of their outputs. Herein, CSA-P1 underscored that research is deeply ingrained within Company A's ethos, with a continuous commitment to seeking novel approaches to enhance material quality. In fact, both CSA-P2, the Strategic Business Development Manager, and CSA-P3, the Environmental Development Manager, mentioned that exploring opportunities for product development and innovation are among their key responsibilities.

Similarly, Company B has dedicated significant resources to research on developing its range of high-quality materials, and this commitment remains a vital component of the company's operations. As expressed by CSB-P1:

> We are permanently in a state of R&D. So, you know, we are always looking at ways to increase the value of the products…looking at ways to provide our customers with a complete range of high-quality recycled construction materials.

Company B's ongoing commitment to research was further supported by CSB-P5, who mentioned that exploring product development opportunities is a crucial aspect of his role as the Sustainable Products Technical Manager.

As part of such research efforts, the two companies have collaborated with government bodies, research institutions, and universities to advance the quality of RCAs to rival or surpass that of virgin aggregates. A review of the company website highlighted that Company A had actively collaborated in Ph.D. projects with university students to explore ways to improve its material offerings. Additionally, Company A had engaged in several trial projects in partnership with DIT South Australia and the Northern Adelaide Waste Management Authority to evaluate the performance of their materials under real-world conditions. CSA-P3 noted that the results from such trial projects have also informed the development of specifications for the use of RCA-based materials in road infrastructure projects in South Australia.

Likewise, according to the company website, Company B has also collaborated with VicRoads, the Commonwealth Scientific and Industrial Research Organisation (CSIRO), the Australian Roads Research Board (ARRB), and RMIT and Swinburne Universities on research to advance the quality of their materials. Company B has worked closely with these entities, conducting rigorous testing over extended durations before releasing its materials to the market. Moreover, Company B has also undertaken several trial projects in partnership with local government authorities in Victoria, which have served as practical applications to assess the quality of the company's materials. Interestingly, CSB-P5 mentioned that Company B has recently collaborated with a mainstream concrete supplier in Australia to develop high-quality concrete mixes containing RCAs, which can be registered for project use. The interviewee noted that Company B, together with the concrete supplier, have developed internal targets to increase the percentage of RCAs in concrete mixes by 2030 and is currently developing inspection and testing plans to meet the stringent quality requirements associated with using RCAs for advanced applications.

The findings affirmed that these research efforts have enabled Companies A and B to improve the quality of their materials while also fostering market confidence. This is evident through the following comment made by CSA-P1 from Company A:

> In the industry that we are in, if we don't keep doing research and development, we are not gonna be able to have that sophistication out there in the market… to convince people that this is a better-quality product actually than virgin material…It's a part of our corporate DNA that we keep innovating, and we keep looking at new ways of developing our products with the waste that comes into us.

Although the findings revealed that Company C's commercial and industrial waste processing arm had been involved in several trial projects, there had been limited opportunities available for the company's DW processing arm to engage in similar endeavours.

A summary of the measures taken by the three companies to assure the quality of their outputs is presented in Table 5.10.

Table 5.10: Summary of measures taken to assure the quality of the outputs [CSA- Company A, CSB – Company B, CSC – Company C]

Measures taken to assure the quality of the outputs			CSA	CSB	CSC	Explanation
	Measure	**Sub-measure**				
Ensuring input quality	Establishing a team to liaise with demolition contractors	-	✓	✓	✓	Establishing a dedicated team to liaise with demolition contractors to make demolition contractors aware of the criteria for waste acceptance and potentially undesirable materials that must be avoided, which ensures the receipt of waste materials of appropriate quality, suitable for producing high-quality outputs
	Charging a quality-based variable gate fee	-	✓	✓	✓	Charging a variable gate fee based on the quality of the incoming waste materials (*i.e., a higher gate fee for unclean waste loads and a lower gate fee for clean loads*) to encourage demolition contractors to provide cleaner, pre-sorted waste loads that can be processed into high-quality outputs
	Implementing a comprehensive input monitoring system	-	✓	✓	✓	Implementing multi-staged systems for monitoring incoming waste to control the influx of undesirable materials that can negatively impact the quality of the output
Minimising quality failures in processing	Processing and testing materials to specifications	Setting up processes to ensure the outputs produced meet industry specifications	✓	✓	✓	Setting up the waste recovery process to ensure that the materials produced comply with industry specifications
		Tailor-made outputs	✓	✓		Developing the ability to produce tailor-made outputs to meet the specifications of a given project
		Periodic testing	✓	✓	✓	Undertaking periodic testing as per the testing requirements stipulated in the specifications following standard Australian test methods through accredited laboratories, with the option for users to request additional testing if required
		Pre-qualification/ accreditation	✓	✓		Obtaining pre-qualification/accreditation for the materials where possible

Measures taken to assure the quality of the outputs			CSA	CSB	CSC	Explanation
Measure		**Sub-measure**				
	Implementing comprehensive sorting and screening systems	-	✓	✓	✓	Setting up comprehensive multi-staged sorting and screening systems to remove any undesirable materials from the incoming waste stream that can affect the quality of the output
	Managing stockpiles to avoid cross-contamination	Maintaining separate stockpiles for different material categories	✓	✓	✓	Maintaining separate stockpiles for different categories of incoming waste materials and outgoing processed materials to prevent cross-contamination
		Establishing protocols to handle hazardous materials	✓	✓	✓	Establishing protocols to handle hazardous materials like asbestos if identified
	Upskilling employees	-	✓	✓	✓	Upskilling all employees involved in the recovery process with the necessary skills to minimise quality issues from materialising
	Opting for third-party accreditation	-	✓	✓	✓	Opting for third-party accreditations (*e.g., ISO 9001*) that promote continuous process improvement, and reduce the likelihood of quality issues materialising
Resolving post-sales quality issues	Implementing systems to capture user feedback regarding material quality	-	✓	✓	✓	Implementing systems to capture negative feedback regarding material quality, to be used as a mechanism for identifying process improvement opportunities to minimise recurring quality failures
Other	Conducting product research to enhance material quality	-	✓	✓		Exploring avenues to enhance material quality through research and trial projects carried out in partnerships with universities, governmental and non-governmental bodies, and suppliers of complimentary materials

5.5.4 Focus area 4: Measures taken to ensure reliable supplies of outputs

The findings highlighted that to ensure reliable supplies of outputs, the case study companies have focused on ensuring continuity of inflows, minimising bottlenecks in processing, and improving distribution capabilities. The measures taken by the case study companies to ensure reliable supplies of outputs are shown in Figure 5.15.

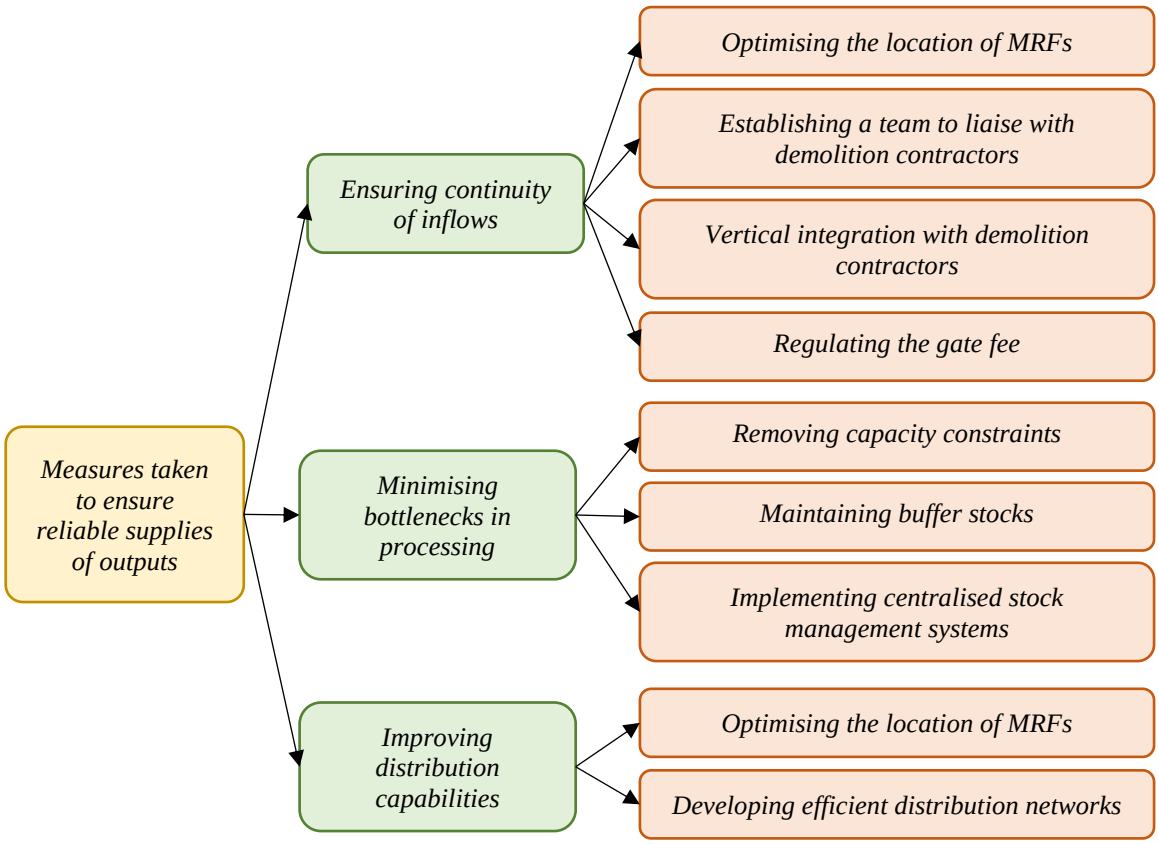


Figure 5.15: Measures taken to ensure reliable supplies of outputs

5.5.4.1 Ensuring continuity of inflows

The case study companies rely solely on the inflow of waste materials to maintain a reliable supply of processed materials. Consequently, they have implemented several steps to ensure a continuous inflow of waste materials. These include optimising the location of MRFs, establishing a team to liaise with demolition contractors, vertical integration with demolition contractors, and regulating the gate fee. These measures are explained in detail in the following sections.

5.5.4.1.1 Optimising the location of MRFs

In the context of optimising the location of MRFs, it is evident from Appendices 1(A), 1(B), and 1(C) that all three companies have strategically located their MRFs in close proximity to metropolitan or major growth areas characterised by high levels of

construction activity, which serve as the primary sources of DW. Furthermore, these locations have been carefully chosen to ensure easy accessibility via well-developed road networks. As shown in Appendix 1(A), the two MRFs of Company A are located to the north and south of Adelaide (the capital city of South Australia), covering the populous northern and southern suburbs where construction activity predominantly takes place. Further, both these facilities are accessible via major roadways. Similarly, as illustrated in Appendix 1(B), Company B has positioned its three MRFs strategically to cover major growth areas in Melbourne (the capital city of Victoria), all connected through an extensive network of arterial roads and motorways. Likewise, as indicated in Appendix 1(C), the MRF of Company C is situated in close proximity to Adelaide and its northern suburbs, where construction activity is high and provides easy accessibility via major roadways.

According to CSA-P3, CSB-P3, and CSC-P6 from Companies A, B, and C, respectively, this strategic positioning of the MRFs has facilitated demolition contractors in conveniently and cost-effectively transporting their waste to MRFs operated by the three companies. This, in turn, has incentivised demolition contractors to opt for MRFs over landfills, which are typically located further away from metropolitan areas. Moreover, given the proximity of the MRFs to metropolitan areas experiencing heightened construction activity, it is likely that a higher number of demolition projects surround these MRFs, enhancing access to waste materials. By following this strategic approach to optimising the location of their MRFs, the companies have bolstered their ability to secure a continuous supply of waste materials for reprocessing. The significance of these MRF locations in ensuring a steady stream of waste materials for processing is underscored by the following comment by CSB-P3 from Company B:

> We need to make sure that our sites are ideally located close enough to the city and the urban growth areas so that it makes economic sense for customers [demolition contractors] to bring their products to us for recycling rather than take it to a nearby landfill. If they have to travel too far, then that doesn't make economic sense.

5.5.4.1.2 Establishing a team to liaise with demolition contractors

As with ensuring input quality, the teams established to liaise with demolition contractors have proven instrumental for the companies in securing a consistent stream of waste materials for processing. These teams scan the market for upcoming demolition projects and engage with the responsible contractors to negotiate access to the waste generated in such projects. This approach was substantiated by the insights provided by CSA-P1 from Company A, who noted:

> If we know that we have a projected sales volume for this month, we have to make sure that there is the waste coming in, and that's what the team does; they scan the market, they do the due diligence, they approach the right people, and make sure we are able to supply.

CSB-P3 from Company B also emphasised the proactive efforts of these teams in establishing connections with major projects and demolition contractors to secure reliable supplies of waste materials for processing. Similarly, CSC-P2 from Company C underscored the market monitoring role of these teams as follows:

> We are trying to keep an eye on the market…through our process there, we know what projects are coming up and who has quoted them, and we make sure whoever who wins that, we knock on their door.

Moreover, the findings revealed that these teams maintain regular communications with demolition contractors to gain insights into upcoming demolition projects, potential volumes of waste that might be generated, and the possibility of accessing such waste materials. CSA-P2 from Company A elaborated on this aspect as follows:

> Our guys will spend a lot of time with our customers [demolition contractors] and get an understanding of what projects they have coming up…if they are a residential demolition contractor, you know, what their next three months look like, if they are busy, how many houses have they got… so, we are always collecting that information.

Similar assertions were made by CSB-P4 from Company B, highlighting their regular interactions with demolition contractors to gather intelligence about forthcoming projects and the quantities of waste materials available for processing. CSC-P2 from Company C also stressed the team's role in maintaining frequent contact with demolition contractors by mentioning that these teams use regular call cycles to connect with demolition contractors to gauge the feasibility of obtaining waste materials from their upcoming projects.

Using the information gathered through these regular interactions, these teams forecast waste inflows, assess their sufficiency to meet the market demand for their materials, and take necessary actions to balance the inflows with the outflows. The vital role of these teams in managing waste inflows and outflows is captured in the following statement by CSB-P5 from Company B:

> It's about ensuring, yeah, being aware of the stock volumes available on site, ready to be processed, and then, you know, managing the incoming; sometimes there's too much, and sometimes there's not enough, so it must be balanced consistently.

As part of this process of liaising with demolition contractors, these teams also offer customised quotations for waste disposal services, provide guidance to demolition

contractors on effective and regulatory-compliant waste management practices, and facilitate the coordination of waste material transportation from demolition sites to MRFs, as needed. Particularly in Company C, CSC-P5 mentioned that the teams also visit demolition sites to advise and support demolition contractors in waste handling. By cultivating strong relationships with demolition contractors through these teams, the companies have succeeded in ensuring a continuous inflow of waste materials for processing, thereby maintaining a reliable supply of outputs.

5.5.4.1.3 Vertical integration with demolition contractors

As another measure for ensuring the continuity of waste inflows, the companies have pursued vertical integration with demolition contractors to obtain exclusive rights to the waste generated by these contractors. The findings highlighted three possible approaches to achieving this integration. The first is through long-term strategic partnerships, observed in Companies A and C. Both Companies A and C have formed strategic partnerships with two major demolition contractors operating in South Australia, granting them exclusive access to all the waste generated by those contractors. According to the company website, Company A has further strengthened this partnership by appointing the Managing Director of the partner demolition firm as a Non-Executive Director of Company A. Through these strategic partnerships, both companies have been able to secure all the waste generated by the two demolition contractors, thereby ensuring better continuity in the inflow of waste materials for processing. CSC-P6 from Company C elaborated on the advantage of developing such partnerships in gaining access to waste materials for processing through the following example:

> Company X [Original company name mentioned by the interviewee was removed for confidentiality reasons] recently completed demolishing the Dental School, a major demolition project at the Lot Fourteen precinct. Because of our partnership with Company X, we got access to all the waste from the project, which we then processed at our site.

By supplying all DW exclusively to Companies A and C, the two demolition contractors benefit from lower gate fees and a boost to their environmental credentials as environmentally responsible demolishers focused on waste recovery. Projecting such a greener outlook, in turn, enhances their prospects of winning demolition contracts. Company B, on the other hand, has not established such long-term partnerships, potentially due to concerns regarding the constraints on operational flexibility that could arise from such arrangements.

The second approach for vertical integration is through price-based agreements, a strategy adopted by all three companies. These agreements have allowed the companies to access all the waste generated by a particular demolition contractor during a specific period at a pre-determined gate fee. CSA-P2 from Company A elaborated on the nature of these price-based agreements as follows:

> There are residential demolishers who just knock over housings for housing development, and they are the guys that we negotiate rates with annually…we'll agree rates for 12 months on the commitment that we get all of their volumes.

These agreements entail reduced gate fees for demolition contractors, thereby incentivising them to direct their DW to the companies instead of opting for other waste processors or landfills. Expanding on this, both CSB-P1 and CSB-P5 from Company B mentioned that these agreements are price-based because it is inherently challenging to predict volumes accurately, which tend to vary depending on the nature and scale of demolition projects undertaken by demolition contractors.

The third approach is through project-level agreements, a practice observed across all three companies. These agreements are primarily used in the case of large-scale demolition projects, ensuring exclusive access to the waste generated in such projects. As per the company websites, some of the notable projects for which the companies had entered into project-level agreements include the demolition of the Harris Scarf Building in Adelaide for Company A, the demolition of the Broadmeadows Woolworths Distribution Centre for Company B, and the redevelopment of the Adelaide Convention Centre for Company C. Similar to the price-based agreements, demolition contractors also benefit from project-level agreements through reduced gate fees compared to standard rates.

5.5.4.1.4 Regulating the gate fee

The findings highlighted that the three companies employ gate fee regulation as a mechanism to secure a continuous supply of waste materials for processing. According to the insights from interviewees across all three companies (CSA-P1 and CSA-P2 from Company A / CSB-P1 from Company B / CSC-P5 from Company C), the gate fee is maintained well below the landfill levies in the states in which these companies operate, thus making it more economical for demolition contractors to take their waste to the MRFs of the companies rather than to landfills. This is best exemplified by the gate fee structure employed by Company A, as shown in Table 5.8 (refer to Section 5.5.2.2.2). According to the table, the current gate fee charged by Company A for clean and unclean concrete is

$49.50/tonne and $60.50/tonne, respectively. In contrast, the landfill levy in South Australia (Applicable from 1 July 2022 – 30 June 2023) for disposing of an equivalent load of solid waste in metropolitan Adelaide is $149.00/tonne (Environment Protection Authority (EPA) South Australia 2023b). This inevitably drives demolition contractors to consider supplying their waste to Company A rather than considering landfills. This significant price differential of nearly 150% inevitably incentivises demolition contractors to opt for the disposal of their waste materials with Company A rather than resorting to landfills.

Furthermore, when the MRFs face shortages of waste materials, the companies take the proactive measure of lowering the gate fee even further, below the rates offered by competitors, to attract additional waste materials for processing. Herein, CSA-P2 from Company A explained that when the company's MRFs are unable to meet the market demand for their materials, the gate fee is decreased to incentivise demolition contractors to supply more waste materials to the facilities. Alternatively, when adequate supplies are available, the gate fee is adjusted upward to maintain a balance between supply and demand. Similar findings were noted from Company B, wherein CSB-P1 and CSB-P4 explained that when the supply of waste materials is low, the gate fee is reduced, occasionally even down to zero, to attract more waste materials into their facilities. Conversely, if the facilities approach capacity and lack sufficient space for stockpiling waste materials, the fee is increased to manage the flow effectively. For example, CSB-P4 pointed out that in 2022, Company B maintained reduced gate fees to secure sufficient waste materials, owing to their limited availability resulting from inclement weather conditions that impeded construction activity. Similar assertions were made by CSC-P5 from Company C, who added that during periods with a limited influx of waste materials, the company would lower the gate fee further below the landfill levy, thereby encouraging demolition contractors to direct their waste to the company's MRF. Collectively, these findings indicate the consideration given by all three companies to gate fee regulations as a suitable measure for ensuring the continuity of waste inflows for processing.

5.5.4.2 Minimising bottlenecks in processing

Following ensuring the continuity of inflows, the case study companies have directed their focus on minimising bottlenecks in processing that can affect the maintenance of supply reliability. In this regard, the companies have focused on removing capacity constraints, maintaining buffer stocks, and implementing centralised stock management systems.

5.5.4.2.1 Removing capacity constraints

The findings indicated that all three companies have progressively improved their processing capacities to accommodate the requirements of even large-scale projects with substantial material requirements. Herein, the companies have invested in state-of-the-art technologies that enhance the efficiency of the waste recovery processes and allow higher waste recovery rates to be achieved.

An overview of Company A available on the company website revealed that it had commenced operations with its Wingfield MRF in 1993, which underwent a major upgrade in 2004 to improve the capacity of its crushing plant. This was complemented by the launch of the company's second MRF at Lonsdale in 2007. The sophistication of the plant and machinery at both these facilities have been improved over the years to achieve the required capacity to cater to the market demand for their materials. CSA-P2 elaborated on the improvement in the company's processing capacity as follows:

> The plant's got a bit better and a bit more sophisticated…the plant is being added on to, over the years. When we first established our business out on that site 30 years ago, we probably did 5000 tonnes a month, and now we do 65,000 tonnes…so, I think we've met the market really well."

As evident from the figures in the above extract, the company is currently capable of producing more than ten times the amount of output per hour compared to the original plant, allowing it to meet the requirements of large-scale projects with substantial material requirements.

According to the company website, Company B has also invested heavily in state-of-the-art MRFs with high production volumes to remove capacity constraints and maintain supply reliability. The company's high-volume plants can readily meet the demands of large-scale construction projects. With multiple facilities in Victoria, the company can also coordinate between these facilities to meet the market requirements, particularly during periods of high demand. CSB-P4 affirmed that the company continues to invest in improving processing capacity as the demand for sustainable construction materials grows and that it is an integral aspect of her role as the Recycling Manager to look at opportunities for such improvements.

Similar to Companies A and B, Company C has also invested in expanding its processing capacity to remove capacity constraints. One significant example of the company's focus on removing capacity constraints is its investment in a high-capacity crushing plant, referred to as a "monster crusher", which has quadrupled the processing capacity. CSC-P1

mentioned that before introducing this "monster crusher", the company could not meet the demand for their materials from large-scale projects. However, with the addition of this new crusher, Company C can now supply even the largest infrastructure projects in South Australia. Moreover, CSB-P1 acknowledged that the company remains committed to integrating new technologies aimed at enhancing the efficiency of the waste recovery process, which improves waste recovery rate and facilitates the improvement of supply reliability; "*New technology allows for greater recycling efficiency of waste fractions and overall recycling rate…it has helped us to significantly improve the recovery of waste*", said CSB-P1.

Interestingly, the analysis of Company A's capability statement and the insights shared by CSB-P3 from Company B revealed that Company A and Company B have built-in spare capacity in their processes to accommodate increased processing requirements during peak periods. This spare capacity serves as an important safeguard to ensure supply reliability even in the event of a surge in market demand. However, it is important to note that while having this extra capacity is advantageous, it comes with a share of considerations, particularly in terms of the added cost of maintaining this capacity during periods where this capacity is not utilised (e.g., when the market is slow or stagnant), which could be the reason why such a measure was not highlighted in Company C.

5.5.4.2.2 Maintaining buffer stocks

The findings underlined that all three companies have focused on maintaining buffer stocks to minimise processing bottlenecks and ensure supply reliability. As explained by CSA-P1 and CSA-P3, buffer stocks of processed materials are maintained by Company A between its two sites located at Wingfield and Lonsdale. According to the interviewees, these buffer stocks were proven crucial for maintaining supply reliability, especially during periods of high demand from large-scale infrastructure projects such as the completion of the Northern Expressway, for which Company A was a major supplier. Similarly, CSB-P3 expressed that Company B has capitalised on the extensive site space of its MRFs to maintain sufficient stockpiles of processed materials to meet market demand effectively. The insights from the interviewee were complemented by a company overview on its website, which highlighted that all processing sites have the capacity to stockpile incoming waste and processed materials to supply even large-scale projects efficiently. Company C has also utilised its spacious site to maintain buffer stocks, which can be used to manage market fluctuations and process disruptions. CSC-P2 elaborated on the advantages of this

approach, emphasising the flexibility afforded by the company's large site in maintaining buffer stocks:

> Our site is very large, so, we are on the whole Wingfield waste, the Wingfield dump site, we are about a million square meters, our site. So, we've got a bit of room there, I mean, and got a bit of flexibility to what we do…We have a lot of material available in advance.

CSC-P2 further explained that during periods with a higher influx of waste materials, the facility extends its operating hours and deploys additional labour to ensure that the materials are processed and the buffer stocks are replenished and maintained at an optimum level.

However, it is important to note that the capacity to maintain buffer stocks is subject to the conditions stipulated in the operating licenses issued for MRFs in different states and reporting requirements, such as mass balance reporting requirements in South Australia. Consequently, buffer stocks must be managed within the requirements outlined in these licenses and reporting requirements. This limitation was highlighted by interviewees from all three companies. The conditions related to stockpiling in the South Australian context were highlighted through the following extracts from the interviews with CSA-P2 from Company A and CSC-P2 from Company C:

> There's certainly limitations from the government around things like stockpile heights… and we are always managing those…There's a mass balance reporting we have to do, so every month, we have to report to the EPA around how much material came in and how much material we manufactured. We are not allowed to take about 200,000 tonnes of material in and only make 20,000 tonnes…we are not allowed to do that" [CSA-P2].

> We've got limits we are allowed to stockpile on site, which we've got to make sure that we are always ahead of the curve of that…Areas we can receive, areas that we've got to keep clear, heights of stockpiles, mass balance reporting, which is something that's come in the last couple of years, is tonnes in versus tonnes out…they are part of our licenses [CSC-P2].

This information was corroborated through a review of the website of the South Australian EPA, which outlines MRFs' monthly reporting obligations regarding materials received, transported, stockpiled on-site, and utilised, along with specific stipulations related to permissible stockpile heights (Environment Protection Authority (EPA) South Australia 2023a).

Similar requirements were identified in the Victorian context, as noted by CSB-P3, CSB-P4, and CSB-P5 from Company B, who concurred that the maintenance of buffer stocks is

subject to processing and stockpiling conditions prescribed in the operating licenses issued by the Victorian EPA. CSB-P4 elaborated on this as follows:

> Each site has an EPA license, and it outlines exactly what you can and can't do at that site…and then you have inspections by the EPA regularly as well, just to make sure you are adhering to that particular license…Those rulings, they can go to how high your stockpile can be for a certain type of product and how many tonnes you can process."

This information was also confirmed through a review of the website of the Victorian EPA, which offers detailed guidelines on the management of stockpiles for various material categories (Environment Protection Authority (EPA) Victoria 2020).

In summary, maintaining buffer stocks was acknowledged as a viable strategy to ensure supply reliability in the face of market fluctuations or process disruptions. However, adopting this measure can be constrained by the conditions specified in operating licenses issued to MRFs and government reporting requirements.

5.5.4.2.3 Implementing centralised stock management systems

Bottlenecks in processing can arise due to discrepancies between material inflows and outflows. CSA-P5 from Company A and CSB-P3 from Company B contended that waste processors rely solely on the waste materials they receive to produce their outputs and should, therefore, strategically match the material inflows with the outflows to maintain reliable supplies. Herein, CSB-P3 commented:

> It needs to be extremely fluid…the incoming needs to really match the outgoing; so, we need to be quite strategic about understanding what materials are coming in and going out.

With this understanding, companies A and B have implemented centralised stock management systems to monitor and take necessary action to balance these inflows and outflows effectively. Insights gathered from the interviewees of the two companies revealed that the two companies had adopted similar systems for centralised stock management.

As explained by CSA-P5 from Company A and CSB-P2 from Company B, up-to-date information regarding material orders and the inflows of waste materials into the MRFs are recorded centrally on these systems by the sales teams and the teams liaising with demolition contractors, respectively. This provides an overview of the potential material inflows and outflows. Based on this information, the production teams then coordinate the waste recovery operations across the different MRFs, and proactive measures are taken in

case any discrepancies between material inflows and outflows are identified. For instance, if the system indicates a potential increase in demand over supply, the companies consider reducing the gate fee to attract more waste materials into the MRFs or tapping into the spare capacity to increase processing volumes. CSA-P5 emphasised the practical value of such a centralised system for Company A, especially when unforeseen changes in processing requirements need to be accommodated; "*The site always changes; what you thought would need five tonnes now would need ten tonnes, and that's where the system comes in handy*", said CSA-P5. Furthermore, both CSB-P2 and CSB-P3 acknowledged that adopting such a centralised system has enabled Company B to improve operational planning and ensure that they meet the tight supply timelines of construction projects. An overview of the centralised stock management system is shown in Figure 5.16.

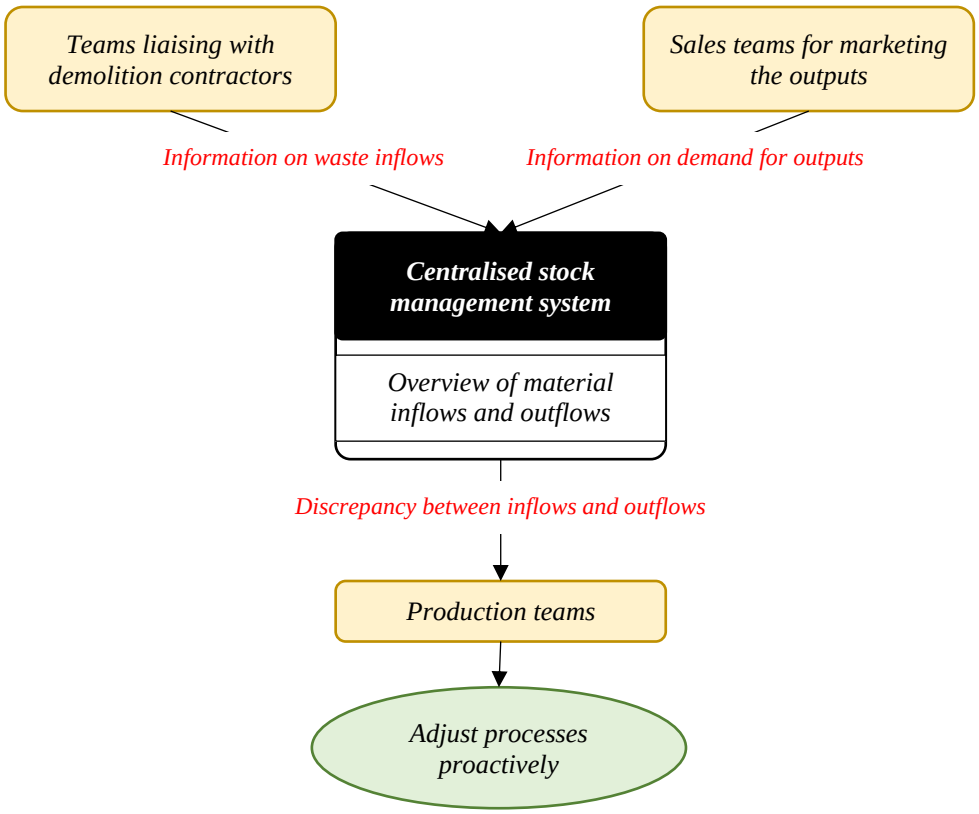


Figure 5.16: Overview of a centralised stock management system

The absence of such a centralised system in Company C could be attributed to the simpler process management within Company C, operating a single MRF as opposed to the multiple facilities operated by Companies A and B.

5.5.4.3 Improving distribution capabilities

The findings revealed that the case study companies had dedicated their efforts to developing their distribution capabilities to improve supply reliability. Herein, optimising

the location of MRFs and developing an efficient distribution network were recognised as measures adopted by the companies to develop their distribution capabilities.

5.5.4.3.1 Optimising the location of MRFs

Similar to ensuring the continuity of inflows, optimising the location of MRFs has enabled the companies to achieve efficient and on-time deliveries. As evident from Appendices 1(A), 1(B), and 1(C) and explained in Section 5.5.4.1.1, all three companies have strategically located their MRFs in close proximity to metropolitan or major growth areas characterised by high levels of construction activity. At the same time, these locations have also been carefully chosen to ensure easy accessibility via well-developed road networks. This strategic positioning of the MRFs has enhanced the capacity of companies to consistently deliver materials efficiently, given that most construction projects are concentrated in these areas. Furthermore, as highlighted by CSB-P2 from Company B and CSC-P6 from Company C, optimising the location of MRFs has become particularly advantageous in light of the increasing distance between sources of virgin aggregates and metropolitan areas. This has allowed the companies to maintain superior delivery performance compared to virgin aggregate suppliers.

5.5.4.3.2 Developing efficient distribution networks

The significance of developing efficient distribution networks capable of fulfilling timely deliveries in line with strict project timelines was recognised across all three cases as a prerequisite for maintaining supply reliability. This was particularly exemplified through the following comment by CSB-P2 from Company B, "*We understand the pressures and timelines on projects, and we do everything we can to make sure our customers get their materials when and where they need them.*" Consequently, all three companies had secured readily available access to a fleet of distribution vehicles and skilled operators through company ownership or third-party contracts, which can be mobilised to fulfil orders promptly. As outlined by CSA-P5 and CSB-P2, Companies A and B manage distribution through a combination of company-owned vehicles and a well-managed pool of competent third-party service providers. This information was corroborated by the capability statement of Company A and the website of Company B. Conversely, CSC-P3 and CSC-P6 noted that in Company C, distribution is primarily managed through competent third parties. These arrangements have granted the three companies access to a diverse fleet of distribution vehicles with different capacities, which can be used to fulfil orders of varying volumes efficiently. Notably, an analysis of the LinkedIn profile and website of Company

B revealed that the company, in response to the shortage of skilled truck drivers in Australia, has also initiated a trainee driver program to recruit and develop talent for operating distribution vehicles, thus further contributing to enhancing the company's distribution capabilities. According to the company websites, both Companies A and B have invested in transport management systems incorporating technologies like GPS, enabling real-time monitoring and scheduling of vehicle movements to ensure timely order fulfilment. However, such systems were not observed in Company C, possibly due to the company's reliance on third-party service providers for most of their distribution.

A summary of the measures taken by the three companies to ensure reliable supplies of outputs is presented in Table 5.11.

Table 5.11: Summary of measures taken to ensure reliable supplies of outputs [CSA- Company A, CSB – Company B, CSC – Company C]

Measures taken to ensure reliable supplies of outputs			CSA	CSB	CSC	Explanation
	Measure	**Sub-measure**				
Ensuring continuity of inflows	Optimising the location of MRFs	-	✓	✓	✓	Optimising the location of material recovery facilities to secure access to sufficient waste materials for processing, to enable demolition contractors to transport waste material conveniently and cost-effectively to material recovery facilities rather than to landfills
	Establishing a team to liaise with demolition contractors	-	✓	✓	✓	Establishing a dedicated team to liaise with demolition contractors and secure a continuous supply of waste materials for processing
	Vertical integration with demolition contractors	Strategic partnerships	✓		✓	Establishing strategic partnerships with demolition contractors as a proactive measure to secure a continuous supply of waste materials for processing
		Periodic price-based agreements	✓	✓	✓	Entering into periodic price-based agreements with demolition contractors to secure access to all waste generated during a specific period at a pre-determined gate fee
		Project-level agreements	✓	✓	✓	Entering into project-level agreements for demolition projects to secure exclusive access to the waste generated in such projects
	Regulating the gate fee	-	✓	✓	✓	Altering the gate fee to regulate the volume of waste materials received in line with the reprocessing requirements (*i.e., decreasing the gate fee when the inflow is limited and increasing it when the inflow is adequate)*
Minimising bottlenecks in processing	Removing capacity constraints	Improve processing capacity	✓	✓	✓	Investing in improving processing capacity to eliminate capacity constraints that limit the ability to maintain reliable market supplies
		Build in spare capacity	✓	✓		Building in spare capacity to accommodate increased processing requirements during periods of peak demand
	Maintaining buffer stocks	-	✓	✓	✓	Maintaining buffer stocks which can be used to ensure supply reliability in the face of market fluctuations or process disruptions

Measures taken to ensure reliable supplies of outputs			CSA	CSB	CSC	Explanation
	Measure	**Sub-measure**				
	Implementing centralised stock management systems	-	✓	✓		Implementing a centralised stock management system for maintaining an up-to-date record of all material inflows and outflows to facilitate necessary action to be taken to maintain an equilibrium between the two flows
Improving distribution capabilities	Optimising the location of MRFs	-	✓	✓	✓	Optimising the location of material recovery facilities to maintain efficient and on-time deliveries of processed materials
	Developing an efficient distribution network	Readily available access to vehicles and operators	✓	✓	✓	Establishing readily available access to a fleet of vehicles and skilled operators, which can be mobilised to fulfil orders on time
		Transport management systems incorporating technologies such as GPS for efficient vehicle scheduling	✓	✓		Using transport management systems that incorporate technologies such as GPS for efficient vehicle scheduling to facilitate on-time delivery

5.5.5 Focus area 5: Measures taken to trace outputs to prior uses

The findings revealed that in all three cases, tracking is limited to the point where the incoming waste materials accepted at the MRFs are stockpiled for further processing. Beyond this point, waste materials cannot be traced to their original sources since waste materials from different sources are placed in the same stockpiles. CSA-P2 from Company A stated, "*We know obviously what we receive and how much we receive and whom we've received it from, but that's the level of our tracking.*" The findings noted that certain specific information regarding the waste loads is recorded when waste materials are accepted at the MRFs. Herein, CSA-P3 and CSA-P5 noted that in Company A, information regarding the incoming waste materials, such as the type (i.e., clean or mixed), weight, source, waste provider, and any contamination observed, are recorded at the weighbridge, and a weighbridge document is prepared for each load with this information and stored in a centralised system. According to CSB-P3 and CSB-P5 from Company B and CSC-P1, CSC-P2, and CSC-P4 from Company C, similar information is recorded by both Company B and Company C regarding the waste loads received. However, the interviewees mentioned that this information is primarily recorded for accounting and reporting purposes, such as mass balance reporting, rather than for tracking waste materials to their origins. CSB-P1 from Company B further highlighted that this information is also recorded for the benefit of demolition contractors supplying waste materials to the company since it enables them to demonstrate the destination of the waste they generated and their commitment to responsible waste management practices. Commenting further on tracking systems, CSB-P1 explained that sophisticated tracking systems are not yet used in the industry for tracking materials as they pass through the waste recovery process.

5.6 A best-practice framework for a user-centric DW recovery process

Collating the findings from the first and second phases of the study, a best practice framework for user-centric DW recovery was developed, as shown in Figure 5.18. Figure 5.17 outlines how the findings from the two phases of the study informed the development of the framework. As noted in Section 5.2, the structuring of user-centric DW recovery processes was conceptualised in this research as a hierarchical pyramid with five sides, representing five focus areas: (1) effective marketing of RCMs, (2) enhancing the cost-competitiveness of RCMs, (3) assuring the quality of RCMs, (4) ensuring reliable supplies of RCMs, and (5) traceability of RCMs to their prior uses. These five areas were identified through the first phase of the study as five focus areas to be considered by waste processors when structuring DW recovery processes in a user-centric manner to meet the requirements

of CPs. During the second phase of the study, which involved undertaking case studies with waste processing companies that produce RCAs from DW, the measures that should be taken by waste processors to achieve the aforementioned focus areas were explored in detail.

Although the traceability of RCMs to their prior uses was identified as a focus area, as explained in Section 5.5.5, findings from the case studies did not reveal any measures that can be used to track RCMs to their previous uses. Therefore, this aspect had to be omitted from the framework since no supporting measures on how such tracking systems should be developed were identified. However, it is noteworthy that future technological advancements, such as digital twins and Radio-Frequency Identification (RFID), may offer the possibility for traceability of RCMs to their previous uses, potentially becoming a crucial component of any waste recovery ecosystem and thus representing an area warranting further research.

With the omission of the aspect related to traceability, the final framework was developed comprising of four sides, as shown in Figure 5.18. In the framework (presented as the top view of a pyramid), the uppermost tier represents the goal of structuring DW recovery processes to be user-centric. The second tier represents four focus areas that waste processors need to concentrate on in achieving the goal of a user-centric DW recovery process. The third tier represents the categorisation of the measures that waste processors should take to achieve the focus areas, while the outermost tier represents the specific measures themselves. The framework is provided with a supplementary document that explains the specific measures in more detail, and the code shown next to each measure relates to its specific explanation in the supplementary document.

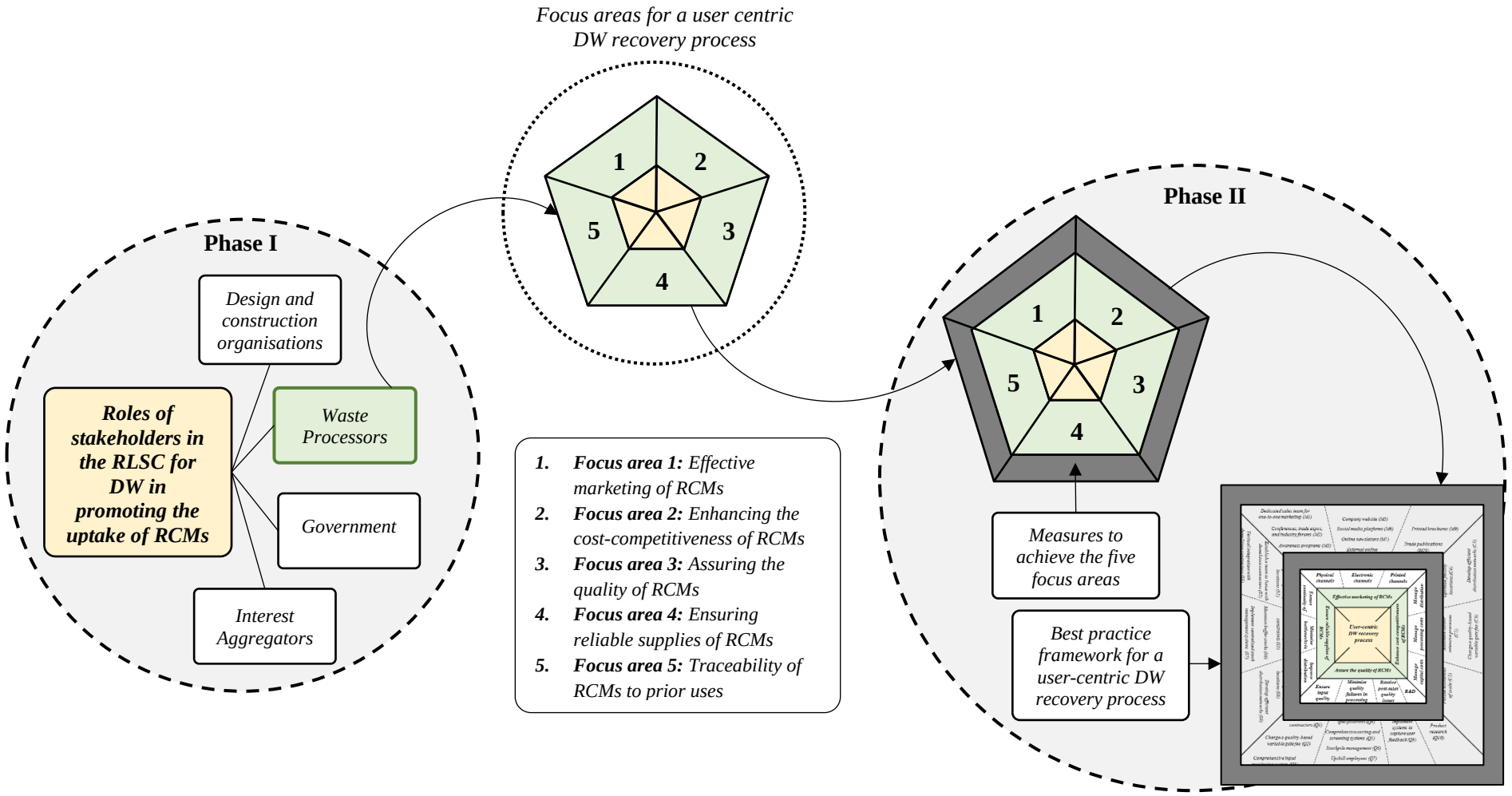
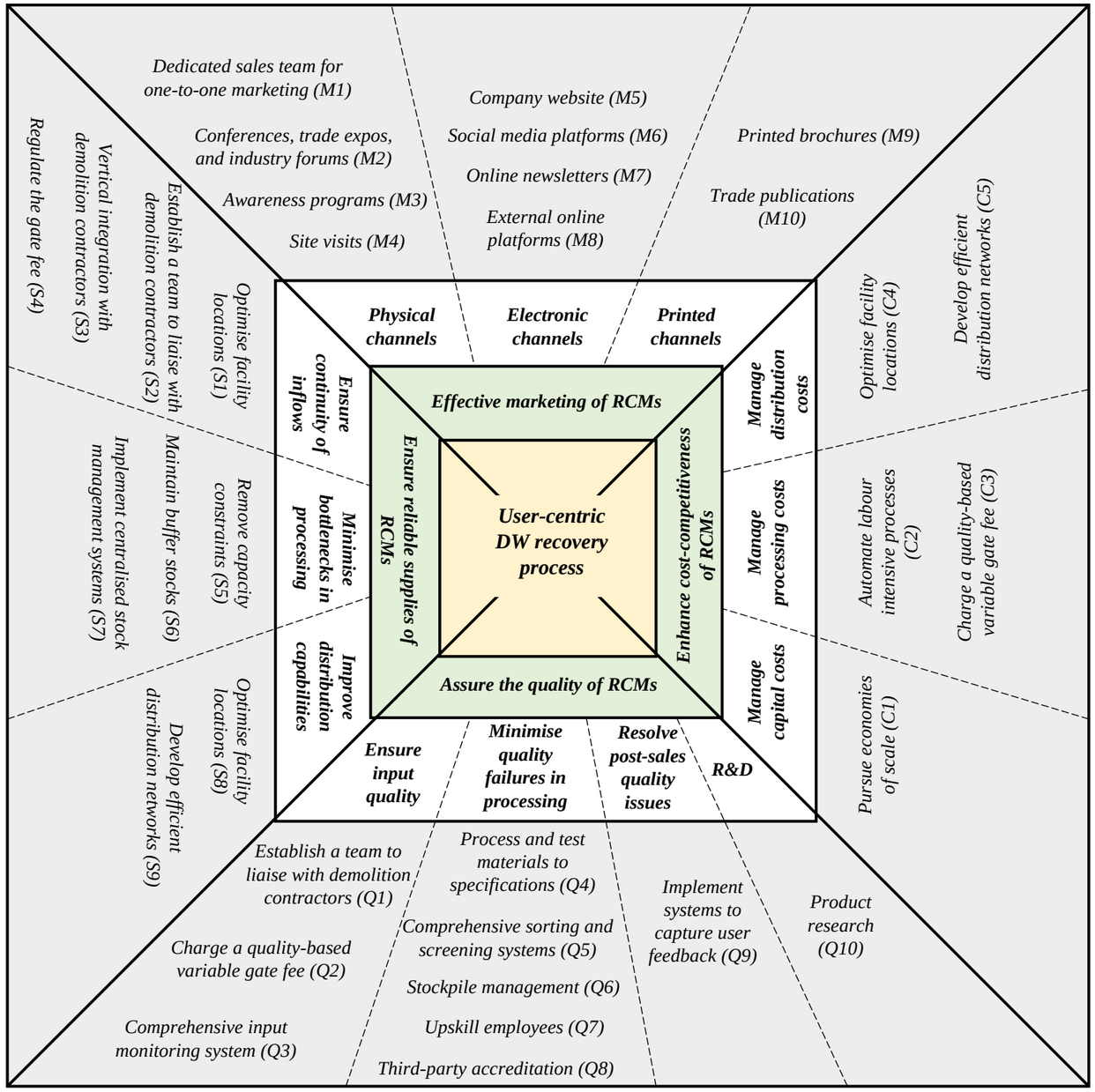
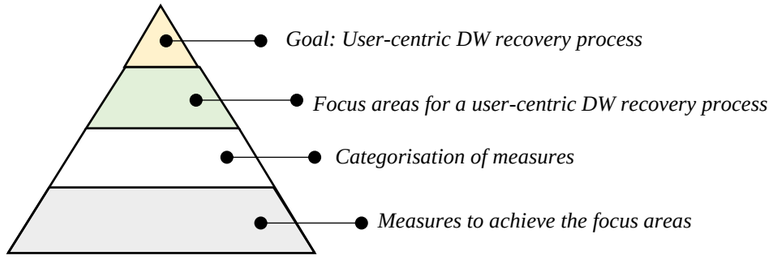


Figure 5.17: Development of the best practice framework for a user centric DW recovery process informed by the findings of phases I and II



LEGEND

The four tiers of the framework



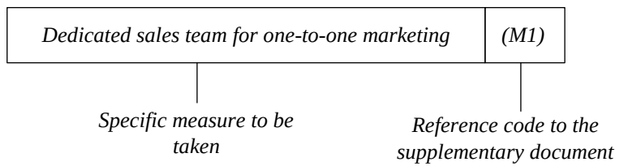
***Notes to the framework*:**

What is a user-centric demolition waste recovery process: *It is a waste recovery processes that is structured to meet the requirements of construction professionals, who are the key end users of reprocessed construction materials.*

To whom is this framework for*: This framework is intended for the use of waste processors. Waste processors can use this framework to structure demolition waste recovery processes in a user-centric manner to meet the requirements of construction professionals.*

The four focus areas (green coloured layer)*: These focus areas reflect the requirements expected by construction professionals from waste processors for them to incorporate RCMs into their projects.*

Referring to the supplementary document: *This framework is intended to be used along with the supplementary document attached. The supplementary document provides detailed explanations of the individual measures (grey coloured layer) in the framework.*



Abbreviations

DW – *Demolition Waste*
RCMs *– Reprocessed Construction Materials*
R&D *– Research and Development*

Figure 5.18: A best practice framework for a user-centric DW recovery process

SUPPLEMENTARY DOCUMENT TO THE FRAMEWORK

Table 5.12: Supplementary document to the framework

Code	Explanation
	Effective marketing of RCMs
M1	Establish a dedicated team for one-to-one marketing, readily accessible to prospective users through different channels (*e.g., email, telephone*) and capable of addressing all user inquiries, including complaints management and provision of post-sales support
M2	Participate in conferences, trade expos and industry forums related to the waste management industry to market materials in a more personalised and interactive manner to large, targeted audiences in a face-to-face setting, whilst also sponsoring such events and participating in panel discussions
M3	Undertake awareness programs in partnership with government bodies, community organisations, and other businesses to enhance awareness about the positive and multifaceted benefits of using the materials
M4	Offer opportunities for interested users to visit the material recovery facilities to witness the process of demolition waste recovery firsthand
M5	Develop a company website that contains pertinent information about the materials (*e.g., material grades and compositions, potential applications, pricing details, comparable virgin alternatives, quality assurance procedures, environmental credentials, previous successful applications and testimonials, an overview of the waste recovery process*) to support material selection, allow the option for making online inquiries, and integrate online ordering systems where feasible
M6	Use social media platforms (*e.g., LinkedIn, YouTube, Instagram*) to post engaging and informative content to make potential users aware of the company and the material offerings
M7	Publish online newsletters to which interested users can subscribe to obtain company updates
M8	Post information about the materials on external online platforms (*e.g., ISupply database of the Infrastructure Sustainability Council Australia*)
M9	Develop printed brochures that contain information about the materials (*e.g., material composition, potential applications, benefits of use, testing results and certifications, quality assurances procedures, previous successful applications, comparable virgin alternatives*) to support material selection
M10	Advertise materials through trade publications specific to the construction and waste management industries
	Enhance cost-competitiveness of RCMs
C1	Design material recovery facilities to operate at optimally high capacities to apportion fixed capital costs across a larger output volume, thereby effectively reducing cost per unit
C2	Minimise the labour involvement and associated labour costs by automating processes where feasible
C3	Charge a variable gate fee based on the quality of the incoming waste materials (*i.e., a higher gate fee for unclean waste loads and a lower gate fee for clean loads*) to reduce/recoup processing costs
C4	Optimise the location of material recovery facilities to minimise the cost of transporting processed materials from these facilities to construction sites

Code	Explanation
C5	**C5.1**: Establish access to distribution vehicles of different capacities, which can be used to fulfil orders of different volumes with minimum truck movements **C5.2**: Use transport management systems that incorporate technologies such as GPS for optimising vehicle scheduling
	Assure the quality of RCMs
Q1	Establish a dedicated team to liaise with demolition contractors to make demolition contractors aware of the criteria for waste acceptance and potentially undesirable materials that must be avoided, which ensures the receipt of waste materials of appropriate quality, suitable for producing high-quality outputs
Q2	Charge a variable gate fee based on the quality of the incoming waste materials (*i.e., a higher gate fee for unclean waste loads and a lower gate fee for clean loads*) to encourage demolition contractors to provide cleaner, pre-sorted waste loads that can be processed into high-quality outputs
Q3	Implement multi-staged systems for monitoring incoming waste to control the influx of undesirable materials that can negatively impact the quality of the output
Q4	**Q4.1**: Set up the waste recovery process to ensure that the materials produced comply with industry specifications **Q4.2**: Develop the ability to produce tailor-made outputs to meet the specifications of a given project **Q4.3**: Undertake periodic testing as per the testing requirements stipulated in the specifications following standard Australian test methods through accredited laboratories, with the option for users to request additional testing if required **Q4.4**: Obtain pre-qualification/accreditation for the materials where possible
Q5	Set up comprehensive multi-staged sorting and screening systems to remove any undesirable materials from the incoming waste stream that can affect the quality of the output
Q6	**Q6.1**: Maintain separate stockpiles for different categories of incoming waste materials and outgoing processed materials to prevent cross-contamination **Q6.2**: Establish protocols to handle hazardous materials like asbestos if identified
Q7	Upskill all employees involved in the recovery process with the necessary skills to minimise quality issues from materialising
Q8	Consider third-party accreditations (*e.g., ISO 9001*) that promote continuous process improvement, and reduce the likelihood of quality issues materialising
Q9	Implement systems to capture negative feedback regarding the material quality, to be used as a mechanism for identifying process improvement opportunities to minimise recurring quality failures
Q10	Explore avenues to enhance material quality through research and trial projects carried out in partnerships with universities, governmental and non-governmental bodies, and suppliers of complimentary materials
	Ensure reliable supplies of RCMs
S1	Optimise the location of material recovery facilities to secure access to sufficient waste materials for processing, to enable demolition contractors to transport waste material conveniently and cost-effectively to material recovery facilities rather than to landfills
S2	Establish a dedicated team to liaise with demolition contractors and secure a continuous supply of waste materials for processing
S3	**S3.1**: Establish strategic partnerships with demolition contractors as a proactive measure to secure a continuous supply of waste materials for processing

Code	Explanation
	S3.2: Enter into periodic price-based agreements with demolition contractors to secure access to all waste generated during a specific period at a pre-determined gate fee **S3.3**: Enter into project-level agreements for demolition projects to secure exclusive access to the waste generated in such projects
S4	Alter the gate fee to regulate the volume of waste materials received in line with the processing requirements (*i.e., decreasing the gate fee when the inflow is limited and increasing it when the inflow is adequate*)
S5	**S5.1**: Invest in improving processing capacity to eliminate capacity constraints that limit the ability to maintain reliable market supplies **S5.2**: Build in spare capacity to accommodate increased processing requirements during periods of peak demand
S6	Maintain buffer stocks, which can be used to ensure supply reliability in the face of market fluctuations or process disruptions
S7	Implement a centralised stock management system for maintaining an up-to-date record of all material inflows and outflows to facilitate necessary action to be taken to maintain an equilibrium between the two flows
S8	Optimise the location of material recovery facilities to maintain efficient and on-time deliveries of processed materials
S9	**S9.1** Establish readily available access to a fleet of vehicles and operators, which can be mobilised to fulfil orders on time **S9.2**: Use transport management systems that incorporate technologies such as GPS for efficient truck scheduling to facilitate on-time delivery

5.7 Validation of the developed framework

The framework developed based on the findings from the case studies was validated using expert interviews. Undertaking such a validation exercise is important if the framework developed is to be used in practice (Preece 2001). In the context of the current study, it is important to clarify that the term "validation" is not employed in a positivist sense, which seeks to establish an absolute truth corresponding to an unchanging social reality (Seale 1999). Instead, it is used to refer to evaluating whether the framework developed would work in practice (Preece 2001). Prior studies have used criteria including ease of understanding, completeness, and usefulness to evaluate the practical applicability of frameworks developed based on the outcomes of qualitative studies (Gunatilake 2013; Kulatunga 2008). According to these studies, ease of understanding looks at whether the framework exhibits clarity and a logical flow of ideas. Completeness looks at whether the framework is comprehensive and has sufficient substance. Usefulness looks at whether the framework is useful and resonates with the experiences of those it is intended for. Drawing from these prior studies, the current study adopted similar criteria to validate the best-practice framework for a user-centric DW recovery process, which was developed based

on the case study findings. The questions asked from the interviewees under the three criteria during the validation exercise are shown in Table 5.13.

Table 5.13: Evaluation criteria and related questions for framework validation

Evaluation criteria	Related questions	
Ease of understanding – Evaluation of ease of understanding considers whether the framework exhibits clarity (i.e., structure, language used) and a logical flow of ideas (i.e., ensuring that there are no significant gaps in logic)	What is your opinion about the structure and clarity of the framework? Is the framework understandable and user-friendly? • Overall presentation • Clarity of language used • Flow/Logic of elements presented in the framework	
Completeness – Evaluation of completeness considers whether the relevant areas in the framework have been covered comprehensively and whether there is sufficient substance within the findings	What is your opinion about the level of coverage of the framework?	Overall (Main sections)
		Section on "Effective marketing"
		Section on "Enhancing cost-competitiveness"
		Section on "Assuring quality"
		Section on "Ensuring supply reliability"
	Do you have any further comments or recommendations regarding the proposed framework – Any aspects that need to be included/deleted/improved within the framework?	
Usefulness – Evaluation of usefulness considers whether the framework is useful for the intended audience and that it resonates with the experiences of those for whom it is intended	What is your opinion about the framework in terms of its usefulness in developing user-centric DW recovery processes? Would you recommend the framework to be used by waste processors to structure their processes in a user-centric manner?	

Four semi-structured interviews were conducted to evaluate the framework according to the abovementioned criteria, wherein two interviewees were drawn from academia and the other two from industry. The profile of the interviewees who participated in the validation of the framework is shown in Table 5.14. These interviewees were selected by following a purposive sampling technique. To be chosen for the validation exercise, the experts needed to possess a comprehensive understanding of both end-user requirements (i.e., the requirements expected by end users of RCMs from waste processors) and DW recovery

processes, since the goal of the framework is to develop user-centric DW recovery processes. As indicated in Table 5.14, all the selected experts had an in-depth understanding of end-user requirement and DW recovery processes, having worked with end users as well as waste processing companies, and were therefore best placed to comment on the possibility of using the framework in practice.

Upon their agreement to participate in the study, the interview guideline (refer to Appendix 2(C)), the developed framework, and the supplementary document were emailed to the selected interviewees before the interviews to ensure they were well-informed about the framework. Before the commencement of the interviews, the interviewees were briefed about the purpose of the framework, its key components, and its development process to ensure that they had a clear and comprehensive understanding of the framework before proceeding further. Each interview was recorded with the consent of the interviewees, transcribed, and analysed following the directed content analysis technique.

Table 5.14: Profile of interviewees for framework validation

Code	Designation	Experience	Highlights
VE-1	Senior Lecturer (Academia)	25+ years	• Senior Lecturer specialising in teaching sustainable design, design history and theory • Researcher and Advocate focused on implementing the circular economy with a particular interest in the role of design in furthering circularity and more sustainable forms of consumption • Former Director of Zero Waste South Australia (now Green Industries South Australia) Centre for Sustainable Design and Behaviour, driving the research agenda of the centre with the involvement of waste processors and users of reprocessed materials
VE-2	Lecturer (Academia)	9+ years	• Lecturer in Construction Management and Building Surveying with teaching experience in Australia and internationally • Researcher in RL with a PhD focused on modelling risks in RLSCs for DW • Former Quantity Surveyor with experience working for construction consultancy and contracting organisations
VE-3	Principal Consultant (Industry)	23+ years	• Principal Consultant with a demonstrated history of working with renewables and environment industry • Active involvement with Australian Council of Recycling, Waste Management Association of

Code	Designation	Experience	Highlights
			Australia, South Australian EPA, and Green Industries South Australia to educate both governments and industry groups in sustainable waste management practices • Former General Manager for a leading waste processing company in SA, involved in developing and maintaining end-user markets for a wide range of reprocessed materials, developing company processes to ensure the reprocessed materials (specifically RCAs) meet industry specifications, and gaining development approvals and EPA licenses
VE-4	Director and Circular Economy Consultant (Industry)	13+ years	• Circular Economy Consultant working in one of Australia's leading waste management, recycling and sustainability consultancies for government, and private and public enterprises, helping businesses and governments to implement more sustainable practices • An active member of the International Solid Waste Association, working on a range of global waste initiatives including developing a nexus between waste generators and waste processors to understand the ultimate destinations of waste materials

In evaluating the ease of understanding of the framework, the interviewees were questioned about aspects regarding the overall presentation of the framework, the clarity of the language used and the logical flow of ideas. In this regard, a predominantly positive response was received from the interviewees concerning the framework's ease of understanding. The interviewees agreed that the overall presentation of the framework is user-friendly, clear and easy to understand. Additionally, they found the language used in both the framework and its accompanying supplementary document to be mostly easy to understand. However, a few reservations were voiced regarding certain terminological choices within the framework. For instance, VE-4 expressed that the term "vertical integration" might not be readily grasped by industry practitioners unless they refer to the detailed explanation of the concept provided in the supplementary document. Moreover, VE-2 suggested that, instead of labelling the fourth category of measures under "measures for assuring the quality of RCM" as "other," it could be more aptly named "research and development" since the sole measure within this category relates to product research (Note that this adjustment has already been incorporated into the framework shown in Figure 5.18).

In evaluating the completeness of the framework, the interviewees were questioned regarding the extent of coverage of the framework, both in terms of its overall structure and the individual sections on effective marketing, enhancing cost competitiveness, assuring quality, and ensuring supply reliability of RCMs. Notably, all interviewees expressed satisfaction with the completeness of the framework, affirming that it effectively captures the key measures that waste processors could use to realise the specified focus areas. They further emphasised that these measures have been adequately explained through the supplementary document to the framework, thereby facilitating a comprehensive understanding of the individual measures. VE-3 specifically appreciated capturing the marketing aspect, considering its importance in developing a positive outlook regarding RCMs, which currently have some stigma attached to their use. The interviewee elaborated on this aspect as follows:

> … it is important that you have considered marketing… it's really critical for reprocessed materials especially because of the stigma attached to it. So, there's more awareness building that needs to happen from the industry, there's a lot of that to be done, and this gives a good understanding of how that can be done… it's that level of who's actually doing the purchasing, you know, Jeff or Sharon, who's buying the material; we need to convince that person.

In terms of the framework's usefulness, all interviewees agreed that the framework is useful for the industry. Particularly, VE-3 and VE-4 highlighted that Australia's waste recovery industry is growing, driven by the country's ambitious net-zero targets for 2030 and 2050 and the escalating government emphasis on efficient resource recovery. The interviewees expressed that this framework would prove helpful for emerging organisations in the DW recovery field, providing them with a good understanding of how they could set up their processes to achieve continued market success. VE-4 elaborated on this as follows:

> There's a big push for circular economy these days, and that's really boosting the waste recovery industry here in Australia. Many companies are joining the scene, especially with those net zero targets for 2030 and 2050. This framework can be a good roadmap for these companies to set up their operations.

Interestingly, as a future development to the framework, VE-1 mentioned that the role of other stakeholders, such as the government, in supporting waste processors to develop their processes in a user-centric manner could be captured. For example, the interviewee highlighted that the successful implementation of the measure "process and test materials as per specifications" could encounter challenges if the required specifications for RCMs were not developed by the relevant authorities and that such measures could be captured as supporting measures.

5.8 Chapter summary

This chapter focused on developing an in-depth understanding of how waste processors can structure the DW recovery processes in a user-centric manner to meet the requirements of CPs. Herein, findings from Phase I revealed five focus areas that should be considered by waste processors when structuring DW recovery processes in a user-centric manner: (1) effective marketing of RCMs, (2) enhancing the cost competitiveness of RCMs, (3) assuring the quality of RCMs, (4) ensuring reliable supplies of RCMs, and (5) traceability of RCMs to prior uses. Phase I findings further suggested that RCAs are more readily used by CPs when compared to other RCMs, a fact that was also supported by recent reports and statistics from the Australian construction industry. Therefore, with this understanding, case studies were undertaken with three Australian waste processing companies that produce RCAs from DW to understand how they have structured their DW recovery process to achieve the five focus areas mentioned above. Following this, a best-practice framework for a user-centric DW recovery process was developed and validated. Although traceability of RCMs to previous uses was identified as a focus area, no measures that can be used to track RCMs to their previous uses were identified through the case studies. Therefore, this aspect had to be omitted from the framework since no supporting measures on how such tracking systems should be developed were identified. This was considered a limitation of the current study. The next chapter presents a discussion of the findings from the two phases of the research.

CHAPTER SIX: DISCUSSION

6.1 Introduction

This chapter discusses the empirical findings presented in Chapter 4 (from the qualitative survey) and Chapter 5 (from the case studies). These findings are critically reviewed from theoretical and practical perspectives by referring to extant literature. This chapter initially discusses the findings related to the factors limiting the uptake of reprocessed construction materials (RCMs) among construction professionals (CPs) and the strategies for promoting the uptake of such materials. Following this, the key focus areas for developing a user-centric demolition waste (DW) recovery process are discussed in detail.

6.2 Factors limiting the uptake of reprocessed construction materials

The first objective of the research was to identify potential factors that limit the uptake of RCMs among CPs, which was achieved through the first phase of the study that followed a qualitative survey approach. Aligned with ABC Theory, the findings from the qualitative survey showed that a mix of personal and broader contextual factors could limit the uptake of RCMs among CPs (refer to Section 4.3). These findings are discussed with reference to extant literature in the following sections.

6.2.1 The influence of attitudes, personal capabilities, and habits as personal factors limiting the uptake of reprocessed construction materials

The current study found that a multitude of attitudinal factors could potentially limit the uptake of RCMs among CPs. Among these attitudinal factors, the inherent risk aversion among CPs was recognised as a limiting factor in shifting from virgin materials to RCMs. Owing to limited evidence and experience with previous successful applications, using RCMs is perceived as a risky endeavour by CPs, thus discouraging them from using such materials. This was corroborated by Moshood et al. (2020) and Zou, Zhang and Wang (2007), who recognised that the inherent inclination among CPs to avoid risks makes introducing change in the construction industry challenging. As further noted through the findings, this tendency poses a greater challenge when using RCMs for high-profile

projects such as large-scale public or commercial developments, where the negative connotations associated with project failures are much higher. These findings suggest that CPs need to be assured that using RCMs would not increase their risks if they are to use RCMs.

The lesser importance assigned to environmental credentials when making material selection decisions was recognised as another attitudinal factor that limits CPs from considering RCMs. The findings revealed that material selection is predominantly guided by economic consideration and ease of access, resulting in environmentally friendly material options like RCMs going by the wayside. The studies conducted by both Oyedele, Ajayi and Kadiri (2014) and Thompson et al. (2010) demonstrated similar outcomes and acknowledged that CPs prioritise working within project budgets whilst generally assigning a lower priority to environmental benefits during material selection. This equally aligns with previous literature on pro-environmental behaviour that has highlighted the lack of environmental concern among actors enacting the behaviours as a dominant attitudinal factor limiting most pro-environmental behaviours (Dobbelstein & Lochner 2023; Steg & Vlek 2009; Stern 2000). Despite the growing interest among CPs in factoring environmental credentials into their material selection decisions, particularly in light of the Australian Government's "net zero emissions by 2050" commitment (Australian Government Department of Industry Science Energy and Resources 2021), this practice is yet to become mainstream. Therefore, there is a need to encourage CPs to consider environmental credentials alongside other criteria when selecting materials for construction projects.

The current study further revealed that the negative perceptions regarding both the inferior quality and higher cost of RCMs also limit CPs from considering such materials. Previous studies by Oyedele, Ajayi and Kadiri (2014) and Caldera, Ryley and Zatyko (2020) have consistently echoed similar findings, underscoring the industry perceptions regarding the inferior quality of RCMs as a significant deterrent for the widespread use of such materials. Further, Johannessen et al. (2021) also acknowledged that higher perceived costs can discourage the use of materials with recycled content. Adding to such studies, the current study revealed that such negative perceptions regarding both the inferior quality and higher costs of RCMs can be reinforced through prior experiences, albeit experienced in a few cases or experienced before a long time ago. Consequently, this can ingrain such perceptions among CPs, rendering them extremely difficult to change, necessitating strong interventions to drive an attitudinal shift.

According to the study findings, the lack of knowledge and skills required for using RCMs and the limited time available to consider RCMs during material selection were recognised as limitations with the personal capabilities of CPs, hindering the widespread use of RCMs. These findings are consistent with previous research from the domain of pro-environmental behaviour, emphasising knowledge as a necessary antecedent of pro-environmental behaviour (Geiger, Dombois & Funke 2018). Furthermore, previous studies have indicated that individuals are more likely to engage in pro-environmental behaviours when they have sufficient time for deliberation and action (Ertz, Karakas & Sarigöllü 2016; Grimmer, Kilburn & Miles 2016). Notably, the current study found that professionals with backgrounds in architecture and engineering tend to possess a greater understanding of RCMs than those from contracting backgrounds. This discrepancy can be attributed to their exposure to sustainable construction concepts integrated into their curricula. However, given the growing involvement of builders in material selection, especially with the rising popularity of procurement methods like Design-and-Build, it becomes imperative to incorporate RCM-related knowledge and skills across diverse built-environment-related disciplines equally. Moreover, considering the limited time available to select materials upfront, information regarding RCMs must also be made readily available to facilitate the selection of such materials.

Previous studies have argued that habits or routines can influence pro-environmental behaviours (Steg & Vlek 2009; Stern 2000). Aligned with such studies, the current study recognised that selecting construction materials can become cued by habits as materials that have proven effective in previous projects are chosen routinely. Consequently, the tendency among CPs to gravitate towards such routinely used materials was found to limit the uptake of RCMs. In supporting this assertion, previous studies have acknowledged that habits or routines among construction actors can make it difficult to change established construction practices (Abarca-Guerrero, Maas & Van Twillert 2017; Blum & Stutzriemer 2007; Yuan 2013). It became evident that habits or routines can act as particularly formidable barriers when attempting to promote the uptake of RCMs among seasoned CPs accustomed to established ways of working, in contexts characterised by repetitive tasks (e.g., volume housing) and where CPs have established relationships with suppliers of virgin materials. This suggests the need for strategies to disrupt the established habits or routines associated with using virgin materials and create a stable and conducive context that allows the use of RCMs to develop into a stable habit or routine.

6.2.2 The influence of broader contextual factors in limiting the uptake of reprocessed construction materials

Although individuals might prefer certain pro-environmental behaviours, ABC Theory states that they will not be widespread unless the context facilitates such behaviours. Consistent with this principle of ABC Theory, the current study identified a multitude of broader contextual factors outside the control of CPs that can limit them from considering RCMs.

The lack of client interest in using RCMs was recognised as a notable contextual factor that could limit CPs from considering RCMs since they have to tailor their projects to meet client requirements. With clients prioritising financial gains over environmental considerations, CPs are compelled to substitute RCMs with low-cost virgin alternatives to reduce project costs to align with client budgets. This is particularly crucial for builders since meeting client budgets is a key determinant of their ability to secure projects (Blum & Stutzriemer 2007; Knoeri, Binder & Althaus 2011). Notably, convincing commercial clients to use RCMs can become more challenging due to their money-driven nature, limited emotional attachment to projects and reluctance to do things differently. Further, with the decisions of CPs being influenced by the practices and procedures of design and construction organisations in which they are employed, a lack of support at the organisational level for using RCMs can also limit CPs from considering such materials. Herein, the findings underscored the importance of entrepreneurial-type managers within organisations who support the initiatives of CPs to use RCMs. This was supported by Li, YY et al. (2014), where the authors noted that overarching organisational factors such as organisational structures and cultures could influence green construction practices among designers.

The study findings highlighted that RCMs, in general, are more expensive than virgin alternatives, making it challenging to use such materials in construction projects that usually operate under tight budgets. This observation is consistent with multiple previous studies that have either found RCMs to be costlier than virgin materials or have shown minimal price differences between the two (Bolden, Abu-Lebdeh & Fini 2013; Jin et al. 2017; Knoeri, Binder & Althaus 2011; Yuan 2017). Consequently, if the project costs exceed the client's budget, CPs tend to substitute expensive RCMs with cheaper virgin alternatives to reduce overall project costs. This action of CPs is justified, considering the fact that it can become difficult to rationalise spending more on a specific material when a less expensive alternative can adequately fulfil the same function.

Among the notable contextual factors limiting the uptake of RCMs is their inferior and inconsistent quality compared to virgin alternatives, exemplified by real-life instances of quality failures highlighted in the study. Previous research has also emphasised issues with inferior quality as a deterrent to the use of RCMs (Oyedele, Ajayi & Kadiri 2014; Yuan 2017; Zhikun, Wang & Zou 2023). The current study recognised that the impact of such quality concerns is more pronounced when RCMs are used for high-level construction applications with stringent quality requirements. Closely aligned with the issues of inferior and inconsistent quality is the lack of certifications and guarantees for ensuring the quality of RCMs. This has made it challenging for CPs to assess the suitability of RCMs for specific applications. As corroborated by Chick and Micklethwaite (2004), the lack of certifications or guarantees introduces uncertainties regarding the composition, durability, and performance of reprocessed materials. Consequently, CPs face increased risk since they would ultimately have to bear the responsibility for any quality failures stemming from using RCMs whose quality has not been certified or guaranteed. Furthermore, quality certifications and guarantees play a crucial role in ensuring compliance with relevant regulations, construction codes and standards, and insurance requirements, a notion supported by Bao and Lu (2020) and Rose and Stegemann (2018). Therefore, a lack of certifications and guarantees makes it difficult to ascertain whether RCMs meet such compliance requirements, especially in commercial settings with stricter compliance requirements. The findings also shed light on the lack of traceability to previous uses as another quality-related factor that could potentially limit the uptake of RCMs among CPs. Traceability to previous uses is deemed important since the origins of inputs used for producing RCMs can vary, subsequently influencing how RCMs are utilised in new applications. This assertion is supported by the findings of Chen, W et al. (2019), where the authors argued that source information is crucial for analysing the composition of waste materials and identifying potential future uses.

The current study revealed difficulties in sourcing sufficient quantities and supply inconsistencies as contextual factors that deter CPs from considering RCMs. The findings echoed that only a few suppliers can consistently supply reasonable quantities of RCMs. This poses a significant challenge, particularly when using RCMs for large-scale projects with substantial material requirements or projects in regional areas with limited sources of supply. Consequently, RCMs would have to be sourced from multiple sources and distant locations, resulting in additional time and costs incurred for material sourcing and higher transportation-related emissions. These findings related to quantity limitations and supply

inconsistencies are corroborated by prior studies, which revealed that compared to supplies of virgin materials, the supplies of RCMs are irregular, rendering them less favoured alternatives for construction applications (NatSpec Australia 2019; Rose & Stegemann 2018).

The study findings highlighted that existing standards and specifications do not adequately cover RCMs. Consequently, CPs face difficulty in determining the suitability of RCMs for specific applications, as corroborated by studies conducted by Hahladakis, Purnell and Aljabri (2020) and Huang et al. (2018). As a result, CPs are compelled to compare RCMs against the standards and specifications developed for virgin materials, which is far from ideal since this approach may overlook the unique characteristics and requirements associated with RCMs. Furthermore, the research findings shed light on the outdated nature of certain specifications and explicit exclusions of RCM usage in some standards and specifications. This finding aligns with Hahladakis, Purnell and Aljabri (2020) and Silva, de Brito and Dhir (2017), where the authors highlighted government restrictions on using RCMs in new construction applications as a limiting factor for using such materials. Moreover, the findings indicated that inconsistencies in standards and specifications across jurisdictions could also limit the widespread use of RCMs, which was exemplified by Ma et al. (2020), who found that different regions in China had distinct materials standards, leading to a potential rejection of materials developed in one region when used in another. Adding to these limitations related to standards and specifications, the findings underscored a lack of clarity regarding the process for obtaining approvals for RCMs, which has made obtaining approvals complicated and time-consuming. Such bureaucratic hurdles in obtaining approvals can discourage CPs from considering RCMs and drive them towards using virgin materials that are more readily approved for use.

6.3 Strategies for promoting the uptake of reprocessed construction materials

The second objective of the research was focused on exploring potential strategies for promoting the uptake of RCMs among CPs, which was also achieved through the first phase of the study. Past literature has classified these strategies, which aim to promote pro-environmental behaviours, such as the uptake of RCMs, into two main categories: informational and structural. The current study identified a multitude of such informational and structural strategies that can be used to promote the uptake of RCMs among CPs (refer

to Section 4.4). These findings are discussed in the following sections with reference to the current literature on the subject.

6.3.1 Informational strategies for promoting the uptake of reprocessed construction materials

Where the limiting factors to the uptake of RCMs among CPs are attitudinal, the use of informational strategies to address such attitudinal limitations has been suggested in extant literature (Klaniecki, Wuropulos & Hager 2016; Steg & Vlek 2009).

Among the most commonly used informational strategies are those targeted at increasing the knowledge base for decision-making. Prior research has shown that a higher level of knowledge regarding pro-environmental behaviours can drive attitudinal changes in favour of such behaviours (Klaniecki, Wuropulos & Hager 2016; Rau, Nicolai & Stoll-Kleemann 2022). Further, in the context of the current study, it can be argued that informational strategies targeted at increasing the knowledge base for decision-making could also be used to address the personal capabilities limiting the uptake of RCMs. This is because such limitations (as explained in Section 4.3.1.2) were found to stem from a lack of knowledge and difficulty in accessing material information promptly.

The current study recognised several informational strategies that could be used to increase the knowledge among CPs about RCMs, which could, in turn, drive CPs to favour RCMs. One such strategy involves obtaining the services of external experts, such as ESD Consultants, a strategy to be implemented at the level of design and construction organisations. These experts, who are more attuned to RCMs, can convince CPs of the significance of focusing on environmental outcomes in material selection and provide expert advice on various aspects such as market availability, prior research, potential applications, and limitations of RCMs. This aligns with the findings of Pullen et al. (2013), who recognised that involving ESD Consultants at the initial stages of a construction project can offer project participants a better grasp of aspects related to sustainable material selection. Moving further, the current study underscored the importance of expert input in addressing knowledge gaps among CPs regarding RCMs and mitigating the perceived risks associated with their use.

Establishing organisation-wide sustainability forums at the level of design and construction organisations was recognised as another strategy to enhance CPs' knowledge of RCMs. Such groups provide a platform for CPs to improve their understanding of RCMs while facilitating the dissemination of knowledge that might otherwise remain confined to

individual professionals. Moreover, they can serve as conduits to support the integration of external sustainability knowledge into design and construction organisations, thereby heightening the awareness of CPs regarding RCMs. Although several real-life examples of sustainability forums were identified during the current study, their role in driving sustainability initiatives, such as promoting the uptake of RCMs, has received limited attention in extant literature.

Previous literature has underscored that effective marketing can also drive pro-environmental behaviours by enhancing knowledge among responsible actors regarding such behaviours (Dobbelstein & Lochner 2023; Vicente-Molina, Fernández-Sáinz & Izagirre-Olaizola 2013). The emergence of concepts like green marketing further supports this viewpoint (Zhang, X & Dong 2020). Aligned with such studies, the current study highlighted that waste processors must effectively market RCMs to promote uptake. Successful marketing endeavours should focus on capturing the attention of CPs and promptly providing them with the required information for selecting RCMs. The findings acknowledged the potential for using both physical and electronic marketing methods, where combining such methods could provide detailed insights about RCMs where necessary while simultaneously capturing the attention of a broader audience. However, a shift towards electronic marketing techniques is suggested due to the convenience of accessing information through electronic platforms, coupled with low marketing costs, which was also affirmed by Durmaz and Efendioglu (2016).

The findings also underscored the significant role of educational institutes in increasing the knowledge regarding RCMs by educating students on using RCMs as part of curricula. This foundational knowledge would enable students to expand their knowledge through practice later. Such educational initiatives would help to inculcate positive attitudes regarding RCMs among budding CPs, thus encouraging them to look beyond the traditionally used virgin materials. This closely mirrors the findings of Vicente-Molina, Fernández-Sáinz and Izagirre-Olaizola (2013), who also support the notion that building knowledge through higher education can lead to improved pro-environmental behaviours, empowering future leaders coming through higher educational institutes to address environmental challenges effectively. Interestingly, the current study revealed that builders display a lower degree of awareness regarding RCM-related concepts compared to architects and engineers, which could be attributed to a potential lack of training regarding such concepts available for builders. Therefore, greater focus should be given to incorporating these concepts into the curricula for builders since they are increasingly

involved in material selection with the emergence of procurement methods such as Design-and-Build.

The current study also revealed a range of awareness-building initiatives that governmental and non-governmental bodies could adopt to enhance the knowledge regarding RCMs among CPs. Government organisations, in particular, can play a significant role by developing guidance materials to support the selection of RCMs. This approach finds support in the work of Wang, Q et al. (2023), who also identified the development of guidelines for RCMs as an effective measure to facilitate the procurement of such materials in the Chinese context. Notably, some government bodies like VicRoads and DIT South Australia have already advanced in this area, and the learnings from these initiatives can be shared with other responsible governmental bodies across Australia. Governmental bodies can also facilitate knowledge exchange forums, such as conferences and presentations, to establish connections between waste processors and CPs. Further, local councils could also provide specialist advice on environmentally responsible material selection through sustainability officers employed by them. Interestingly, such strategies have not been highlighted in extant literature. At the non-government level, the findings highlighted that professional institutes could organise CPDs and forums for knowledge sharing to educate CPs about RCMs and equip them with the skills required for working with such materials. CPDs are deemed effective since CPs are required to complete specific CPD hours annually to maintain their membership. The active role that professional institutes can play in promoting the uptake of RCMs was also supported by Oyedele, Ajayi and Kadiri (2014), who noted that such institutes could take the initiative to improve awareness regarding RCMs and their benefits among their members. Furthermore, sustainability organisations such as the Green Building Council of Australia (GBCA) and the Infrastructure Sustainability Council of Australia (ISCA) can also contribute by organising knowledge-sharing events, developing guidance materials, and supporting waste processors in promoting RCMs among their members. While prior literature has acknowledged the role of sustainability rating bodies in developing rating tools to support RCM use (He et al. 2022; Oyedele, Ajayi & Kadiri 2014; Shooshtarian et al. 2020b), their contribution towards expanding the knowledgebase around RCMs has been underrepresented.

The current study further recognised the need for developing a centralised database for RCMs, which could be developed by either a governmental or non-governmental body. Such a database could facilitate quick and easy access to information and make sourcing

RCMs more straightforward in competitive construction environments. The importance of information support through such databases in furthering the use of RCMs was affirmed by Oyedele, Ajayi and Kadiri (2014) and Rose and Stegemann (2018), who investigated recycled and reused material marketplaces in the UK. This research expanded on the findings of such studies by identifying specific information that should be included in such a database.

Apart from increasing the knowledge base for decision-making, informational strategies also involve modelling recommended behaviours to drive individuals to emulate similar behaviours (Abrahamse et al. 2005; Michie, van Stralen & West 2011; Rau, Nicolai & Stoll-Kleemann 2022; Steg & Vlek 2009). Consequently, the current study identified modelling the use of RCMs through reference projects as an informational strategy for promoting the uptake of RCMs among CPs. This involves demonstrating the practical applications and benefits of using RCMs through reference projects to encourage and boost confidence among CPs to adopt similar methodologies. Supporting this notion, Ding, Nie and Wu (2022) also highlighted that governments can publicise construction projects that have used RCMs as demonstration projects. As supported by the authors, this research also recognised governmental bodies as suitable entities to implement this strategy since they undertake many construction projects that can serve as exemplars for RCM usage. Interestingly, some government infrastructure projects, such as Victoria's Big Build, have already prioritised using RCMs (Victoria's Big Build 2022), and the learning from such projects can, therefore, be shared across the industry. In addition to governmental bodies, sustainability organisations can contribute by disseminating information about successful sustainability-rated projects that have used RCMs that can serve as reference projects for CPs to emulate.

Prior research supports using commitments as an informational strategy to induce positive changes in pro-environmental behaviours (Abrahamse et al. 2005; Klaniecki, Wuropulos & Hager 2016; Steg & Vlek 2009). Herein, written and public commitments have been found to be more effective than oral and private commitments (Klaniecki, Wuropulos & Hager 2016). Accordingly, the current study revealed that professional institutes can encourage their members to make written public commitments to use RCMs. The public nature of such commitments creates social pressure on CPs, driving them to follow through with their commitments and take necessary action to increase the use of RCMs in their professional practice. Previous research has demonstrated the effectiveness of commitment strategies in advancing pro-environmental behaviours related to recycling, energy

conservation, and sustainable transportation (Fisher & Irvine 2016; Klaniecki, Wuropulos & Hager 2016; Rau, Nicolai & Stoll-Kleemann 2022; Werner et al. 1995). Building upon such studies, it can be inferred that commitments present a promising strategy for promoting the uptake of RCMs among CPs.

Feedback, which involves providing individuals with insights about the outcomes of a specific behaviour after it is performed, has been recognised as an informational strategy for encouraging pro-environmental behaviours (Klaniecki, Wuropulos & Hager 2016; Rau, Nicolai & Stoll-Kleemann 2022). Accordingly, the current study underscored the potential for governmental and non-governmental bodies to develop tools to provide CPs with feedback regarding the positive environmental impacts of using RCMs. Herein, tools could be developed to calculate environmental impact indicators such as carbon emissions linked to using different RCMs versus their virgin counterparts, thereby discerning the environmental advantages of opting for RCMs and prompting CPs to provide greater consideration for RCMs during material selection. Similar feedback strategies have often been used in the domains of energy and water conservation (Abrahamse et al. 2005; Fielding et al. 2013; Rau, Nicolai & Stoll-Kleemann 2022). Notably, the findings highlighted that ISCA had developed a calculator for assessing carbon emissions and lifecycle impacts of traditional construction materials, which can serve as a starting point for developing similar tools targeting RCMs.

Credibility building has also been recognised as an informational strategy for promoting pro-environmental behaviours, involving the dissemination of information via trusted sources to increase the likelihood of the information being acted upon by the target audience (Stern 1999, 2000). In line with this idea, the current study identified that the confidence of CPs in embracing RCMs can be improved by providing reliable information from trusted sources. Herein, the findings emphasised the significance of RCMs being endorsed by trusted governmental and non-governmental bodies. Such endorsements, particularly from governmental bodies, have been empirically shown to enhance the likelihood of individuals taking up pro-environmental behaviours such as energy retrofitting (Stern 1999). Moreover, research was recognised as pivotal in building credibility for RCMs. The findings emphasised the vital role of publicised research in bolstering market confidence regarding RCMs, which was affirmed by Shooshtarian et al. (2020b). Certain governmental and non-governmental bodies in several states across Australia already drive research into RCMs primarily used for infrastructure applications.

These initiatives can potentially be expanded to cover RCMs used in building applications as well.

6.3.2 Structural strategies for promoting the uptake of reprocessed construction materials

According to previous literature on pro-environmental behaviour, structural strategies are aimed at addressing the contextual factors and habits or routines that limit pro-environmental behaviours (Klaniecki, Wuropulos & Hager 2016; Steg & Vlek 2009; Verplanken & Wood 2006). Structural strategies involve modifying physical, technical, and organisational systems to change the availability and viability of different pro-environmental behavioural alternatives or implementing specific legislative and policy strategies to regulate the performance or non-performance of pro-environmental behaviours (Klaniecki, Wuropulos & Hager 2016; Li, YY et al. 2014; Steg & Vlek 2009).

Under structural strategies, embedding sustainable material use as a priority consideration within the organisational methodology was recognised as a strategy to be implemented by design and construction organisations in promoting the uptake of RCMs among CPs. Such an approach would encourage CPs to consider sustainable material options like RCMs at the outset of a project and discuss with clients the viability of proceeding with such alternative material options. This is supported by Li, YY et al. (2014) and Ramos and Martinho (2022), who recognised establishing supportive organisational structures and cultivating interest at the organisational level as requisites for driving green construction practices.

The findings underscored that budget constraints faced by construction projects often lead decisions around materiality to be heavily influenced by cost considerations. Thus, waste processors who supply RCMs to the market are required to take necessary actions to ensure that the costs of RCMs are comparable to those of virgin alternatives. Aligned with these findings, Oyedele, Ajayi and Kadiri (2014) explained that waste recovery processes should be value-engineered to minimise process costs, thereby providing a cost-benefit in considering reprocessed-over-virgin. Furthermore, Ding, Nie and Wu (2022) acknowledged the importance of waste processors improving their processes to enhance the economic value of RCMs. Once the economic benefit of using RCMs becomes prominent, the likelihood of such materials being used will likely increase naturally, with cost being a key criterion for material selection.

The current study highlighted that unless the quality of RCMs is on par with virgin materials, CPs would be reluctant to nominate such materials since they would ultimately be held responsible for any quality failures. Consequently, waste processors must focus on assuring the quality of RCMs to promote their uptake. This notion was corroborated by Ramos and Martinho (2022), who emphasised that RCMs must guarantee at least the same quality as virgin alternatives to warrant their use in construction applications. The findings emphasised the significance of reorganising the waste recovery industry as a specialised industry with better quality control procedures to ensure RCMs have superior and consistent quality. This reflects the findings of Jayasinghe, Rameezdeen and Chileshe (2022), which underlined the intrinsic link between the inferior quality of RCMs and customer dissatisfaction, thus emphasising the importance of improving quality across the entire DW recovery process.

As part of their efforts in promoting the uptake of RCMs, the findings emphasised that waste processors must focus on ensuring reliable supplies of RCMs to cater to the requirements of fast-paced and complex construction projects. This requires waste processors to structure their processes to ensure sufficient quantities of RCMs can be sourced consistently, as and when demanded by the market. This resonates with the findings of Iacovidou and Purnell (2016) and Rose and Stegemann (2018), who reinforced the importance of eliminating supply inconsistencies that could otherwise restrict the use of RCMs to small or informal projects. Moving beyond these studies, the current study highlighted that waste processors must ensure that materials can be sourced from a single source rather than collecting small quantities from multiple sources, which can be costly, time-consuming, and result in high transportation-related emissions, thus negating the environmental benefits of using RCMs.

The findings further emphasised that waste processors must develop systems to facilitate traceability of RCMs to prior uses. This can inform CPs whether the RCMs have undergone questionable uses in their previous lives, thus mitigating the risk of quality failures associated with using materials from unknown origins. Bao, Lee and Lu (2020) affirmed the need for source traceability, where the authors identified birth certificates proving material origins as a prerequisite for material selection in Hong Kong-based construction projects. The current study underscored that traceability is crucial when opting for sustainability ratings such as Green Star and LEED, which demand a good audit trail of materials. This augments the need for source traceability of RCMs since sustainability-rated projects are more likely to use RCMs over conventional projects.

The findings underscored the pronounced influence that standards and specifications have on the decision of CPs in selecting construction materials. This notion was corroborated by Gálvez-Martos et al. (2018), wherein the authors acknowledged that CPs rely on sound standards and specifications to support advances in the construction industry, particularly due to their legal liability regarding the end product. Consequently, it is imperative to develop up-to-date standards and specifications for RCMs in order to promote their use among CPs. Standards and specifications must be tailored exclusively to RCMs since those developed for virgin materials might not adequately capture the specificities related to RCMs. For instance, specifications for RCAs would have to incorporate provisions around asbestos testing, given their derivation from DW, a consideration less pertinent to virgin aggregates extracted from untapped quarry sources. Interestingly, the current study revealed that specifications for RCMs should ideally be performance-based rather than recipe/prescriptive-based, which has not been acknowledged in previous research. Developing performance-based specifications was advocated since they allow for a more comprehensive range of RCMs to be considered for achieving a specific performance outcome.

The current study revealed that the state-based development of standards and specifications for RCMs in Australia has led to limitations in their broader applicability nationwide. Therefore, the need for developing these standards and specifications at the national level to ensure their applicability across multiple jurisdictions was recognised. This viewpoint was substantiated by the work of Ma et al. (2020) and Gálvez-Martos et al. (2018), who acknowledged the significance of developing harmonised standards and specifications, both at the national level and at the level of regional blocks such as the EU, for material trade transcending state and national borders. Notably, the findings revealed that infrastructure specifications in Australia have become more attuned to RCMs recently, which was corroborated by several industry reports (Clark et al. 2022; Maqsood et al. 2020; Pickin et al. 2020). However, building standards and specifications were found to be lagging in this area, thus needing to be amended to accommodate RCMs.

Previous literature has shown that altruistic motives might not always suffice to drive pro-environmental behaviours and often necessitate backing through incentives (Teo & Loosemore 2001). Consequently, the findings emphasised the potential of government incentives to promote the uptake of RCMs among CPs. Firstly, the requirement to use RCMs could be included as a tender evaluation criterion with a higher weightage when calling tenders for government projects. This would motivate CPs to consider RCMs when

tendering for government projects. The findings advocated that drawing from the "Local Industry Participation Plan[3]" framework adopted by most states, a comparable approach could be applied by awarding projects to tenderers proposing greater substitution of virgin materials with RCMs. Moreover, upon project award, the use of RCMs could be included as a key result area in contracts, and project teams can be assessed against such criteria and rewarded financially. While existing literature has acknowledged incentivisation strategies like the prioritisation of building permits complying with specific green building standards by local governmental bodies (Sterk 2023), the explicit use of tender evaluation criteria and key result areas in contracts to incentivise the use of RCMs has not been well founded in the literature. Secondly, the government can use pricing policies to enhance the economic appeal of RCMs when compared to virgin alternatives. This could involve offering subsidies or rebates for using RCMs, similar to those currently offered for rooftop solar and battery systems in Australia (Canstar Blue 2018), thereby decreasing the cost of using RCMs. Alternatively, taxes could be imposed on virgin materials to increase their costs, particularly when a reprocessed alternative is readily available. A prominent example is the UK aggregate levy, which has been imposed to encourage the use of RCAs over virgin aggregates (Silva, de Brito & Dhir 2017). Similar levy schemes can also be considered in the Australian context since the supply of RCAs was found to be more developed than other RCMs (Maqsood et al. 2020; Pickin et al. 2020; Sustainability Victoria 2020). For CPs, these pricing policies offer a means to incorporate RCMs into projects while adhering to client budgets. Further, it relieves them from the burden of persuading profit-driven clients who are not interested in using RCMs to consider using such materials.

Mandates can also be used to promote the uptake of RCMs among CPs. Such mandates can drive CPs reluctant to use RCMs to consider their use while simultaneously relieving CPs from the burden of convincing clients who are otherwise not interested in using RCMs. This notion was corroborated by Shooshtarian et al. (2020a), where the authors highlighted that governments could introduce mandatory policies such as sustainable procurement targets to drive the uptake of RCMs. Mandates must be introduced progressively, commencing with public-sector projects over which governmental bodies have more control and subsequently extended to private-sector projects. However, it is crucial to

[3]The Industry Participation Plan is “a document that outlines how the head contractor’s approach to procurement will ensure that full, fair and reasonable opportunity is afforded to local businesses during the design and procurement cycle” – Department of Commerce, Government of Western Australia. This will be considered when selecting contractors for government projects.

exercise caution when implementing mandates, considering their potential counterintuitive effects in cases where the supply of RCMs is underdeveloped.

Further, the findings asserted that governmental bodies responsible for approving materials must provide a clear pathway for obtaining approvals for RCMs not covered under current specifications. The absence of well-defined guidelines around the approval process tends to drive CPs towards opting for virgin materials, which they are confident of being approved for use. Previous studies have not captured this novel finding. Finally, allocating higher credits for using RCMs in sustainability rating tools such as Green Star and ISCA was revealed as a strategy to be implemented by sustainability organisations to promote the uptake of RCMs. Such initiatives can boost the uptake of RCMs since these ratings are increasingly being sought after by both public and private sector projects. This requirement has already been captured to a certain extent through the Green Star rating system that focuses on whole-life analyses and minimising embodied emissions, which could be achieved using RCMs.

6.4 Developing user-centric demolition waste recovery processes

Prior research has recognised that waste processors must structure DW recovery processes in a user-centric manner to meet the requirements of CPs responsible for selecting materials for construction projects (Jayasinghe, Chileshe & Rameezdeen 2019; Liu et al. 2020; Tennakoon, Rameezdeen & Chileshe 2022b). Therefore, a best-practice framework for a user-centric DW recovery process was developed (refer to Figure 5.17) based on findings from the case studies undertaken during the second phase of the study (refer to Chapter 5). This framework outlined four focus areas for a user-centric DW recovery process: (1) effective marketing of RCMs, (2) enhancing the cost-competitiveness of RCMs, (3) assuring the quality of RCMs, and (4) ensuring reliable supplies of RCMs (refer to Figure 6.1). Findings regarding these four focus areas are discussed in relation to extant literature in this section.

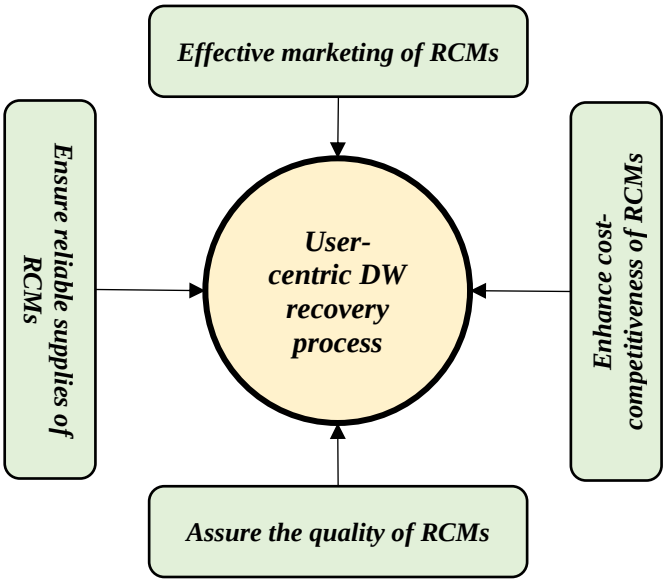


Figure 6.1: Focus areas for a user-centric demolition waste recovery process

6.4.1 Marketing for user-centric demolition waste recovery

With CPs expecting waste processors to promptly provide the required information for selecting RCMs, marketing was recognised as a key focus area for a user-centric DW recovery process. Marketing can be undertaken through various physical, digital, and print channels. Under physical channels, considering the relationship-based nature of material sourcing in the construction industry, the significance of personalised marketing through dedicated sales teams was recognised. This personalised marketing approach, which resonates with the key tenets of relationship marketing (Christopher, Payne & Ballantyne 2013), contributes to cultivating stronger user relationships, improving awareness, and instilling greater confidence in the materials offered, thereby bolstering the market acceptance of RCMs.

While not as pronounced as the impact achieved by dedicated sales teams, other physical marketing channels also provide waste processors with the means to establish a stronger rapport with users by marketing their materials in a more personalised and interactive manner. For instance, participation in conferences, trade expos, and industry forums creates opportunities for engaging with large, targeted audiences through face-to-face interactions. However, as substantiated by Vitali et al. (2022), the efficacy of marketing endeavours through such industry events hinges on the marketer's capacity to sustain continuing connections with users in the post-event phases. Therefore, waste processors must adopt appropriate measures to ensure the sustenance of the user relationships built at these events. In addition, site visits can play a crucial role in fostering user confidence by

offering a first-hand encounter with the organised transformation process followed in producing RCMs and countering negative perceptions about the quality of RCMs. Moreover, implementing awareness campaigns in collaboration with governmental entities, community organisations, and other businesses can augment the awareness of RCMs among a broader audience, transcending beyond the immediate end-users.

In conjunction with physical marketing channels, the current study revealed a range of electronic marketing channels that waste processors could adopt, including websites, social media platforms, online newsletters, and external online platforms. These electronic marketing channels use the internet as a platform to communicate product information and allow waste processors to communicate product information to larger audiences at relatively lower costs. Sheth and Sharma (2005) affirmed these benefits of electronic marketing channels by highlighting their cost-effectiveness in contrast to alternatives like in-person sales representatives and their ability to transcend temporal and locational constraints, thereby rendering otherwise inaccessible user segments accessible. The findings revealed the emergent use of social media platforms as a novel approach for marketing RCMs. Recent studies also substantiate the advent of social media as a growing marketing channel driven by the expanding user base, cost-efficiency, and the potential for two-way communications (Alves, Fernandes & Raposo 2016; Chatterjee & Kumar Kar 2020). Notably, the findings revealed that LinkedIn's professional social media platform is particularly impactful for marketing RCMs due to its objective of cultivating professional connections. The possibility of integrating interactive elements like infographic videos within electronic channels, such as websites and social media, makes such channels particularly useful in facilitating enhanced user engagement.

Interestingly, the current study revealed that it might be possible to integrate online ordering systems into company websites, enabling potential users to check real-time stock availability and place orders online. Such an approach can streamline the material sourcing process for users, a crucial aspect in construction environments characterised by tight project timelines. Moreover, waste processors can consider marketing their materials through external online platforms. However, the feasibility of adopting such an approach depends on the availability of platforms dedicated to RCMs, which were found to be limited in the Australian context (Shooshtarian et al. 2022b). The findings recognised that printed marketing channels, including printed brochures and trade publications, can also be used to market RCMs. Specifically, trade publications from domains such as construction and waste management provide an avenue to market RCMs to targeted audiences

interested in the specific industry niche. However, using such printed channels does not align well with the sustainability values expected to be upheld by waste processors.

6.4.2 Cost competitiveness for user-centric demolition waste recovery

In order to use RCMs, CPs expect waste processors to ensure that RCMs are cost-competitive and economically viable compared to their virgin counterparts. Consequently, a user-centric DW recovery process must be structured to ensure that the outputs produced are cost-competitive. In this regard, the current study recognised that a user-centric DW recovery process should prioritise managing three cost categories: capital costs, distribution costs, and processing costs, identified as the main cost drivers of a DW recovery process.

Prior research has acknowledged that capital costs play a crucial role in establishing MRFs and significantly influence the economic viability of waste recovery schemes (Agrawal, Singh & Murtaza 2015; Dowlatshahi 2005; Govindan & Bouzon 2018). This notion is equally applicable in the Australian context concerning the production of RCMs, where the current study found that high capital costs are incurred for securing site space, obtaining approvals, and acquiring and setting up the required plant and equipment. Notably, in the Australian context, specialised waste recovery plants and equipment must also be imported, further augmenting the capital outlay. Recouping these high capital costs translates to high unit costs for RCMs, potentially diminishing their competitiveness against virgin alternatives. Hence, to bolster the cost competitiveness of RCMs, the pursuit of economies of scale was emphasised. This entails designing MRFs to operate at optimally high capacities to apportion fixed capital costs across a larger output volume, effectively reducing the cost per unit of output produced. Such reductions in unit cost, in turn, allow the outputs to be offered at competitive prices. Similar assertions were noted by Silva, de Brito and Dhir (2017) and Ulubeyli, Kazaz and Arslan (2017), who recognised that while high-capacity MRFs necessitate greater initial investments, the resultant lower unit costs achieved through economies of scale outweigh those of lower-capacity counterparts, thus enhancing the cost competitiveness of the outputs. However, a cautious approach should be followed in pursuing economies of scale, considering the inflow of waste materials for processing and the demand for RCMs. A failure to align these factors appropriately could result in high costs of maintaining excessive redundant capacities, which is counterintuitive.

Continuing the discussion on cost competitiveness, the study findings underscored the significance of managing processing costs to ensure the cost competitiveness of RCMs. This was affirmed by previous studies, notably Guarnieri, e Silva and Levino (2016) and Yeheyis et al. (2013), which recognised that ensuring the economic feasibility of waste recovery schemes depends on the extent of processing required to condition the materials according to market needs. The current study specifically draws attention to labour cost as a main driver of processing costs within the context of reprocessing DW, owing to the labour-intensive nature of this process. Therefore, automating labour-intensive processes where feasible was recognised as an avenue for minimising processing costs. This finding was corroborated by Silva, de Brito and Dhir (2017), who emphasised the economic implications of labour-intensive manual waste recovery and advocated for incorporating automation into such processes. The current study further acknowledged that the imperative for automating labour-intensive processes is exacerbated by the high labour rates in Australia. However, certain stages of the DW recovery process, such as waste sorting, present challenges for full automation due to the substantial variability of incoming waste streams. Until more sophisticated sorting technologies, underpinned by concepts like computer vision, come into play (Zhang, S et al. 2021), achieving full automation within the DW recovery process is less viable. Consequently, until such technologies are introduced to facilitate full automation, effective man-machine combinations should be used to manage labour costs adeptly to offer cost-competitive outputs to the market. Further, the current study identified the gate fee levied on demolition contractors upon delivering waste materials to MRFs as a noteworthy avenue for waste processors to manage their processing costs effectively. This gate fee, which is varied based on the quality of the waste materials, serves as a revenue stream that waste processors can leverage to offset their processing costs, thereby maintaining competitive pricing for RCMs.

Alongside processing costs, distribution costs were also recognised as another significant cost component that needs to be managed by waste processors to improve the cost competitiveness of RCMs. This resonates with prior research across various sectors, such as apparel, electronics, and polystyrene packaging, where the strategic management of distribution costs assumed a pivotal role in shaping the development of RLSCs (Abraham 2011; de Oliveira, Luna & Campos 2019; Hung Lau & Wang 2009). The current study recognised optimising the location of MRFs in proximity to metropolitan areas with high construction activity, as well as being accessible via major road networks, as a viable

approach for minimising distribution costs. This assertion is substantiated by the observations of de Oliveira, Luna and Campos (2019), who noted that the strategic location of MRFs in proximity to demand hubs by processors of waste polystyrene packaging in Brazil has contributed to reducing distribution costs. The current study further revealed that, particularly within the Australian context and with specific reference to RCMs, optimising the location of MRFs bears substantial advantages due to the shifting locations of virgin material sources like aggregate quarries away from metropolitan areas, consequently leading to an escalation in transportation costs linked to using virgin materials. Distribution costs can also be minimised by utilising a fleet of vehicles with different capacities to fulfil orders of varying volumes while optimising vehicle movements through efficient transport management systems.

6.4.3 Quality assurance for user-centric demolition waste recovery

With CPs expecting waste processors to ensure that RCMs have superior and consistent quality, assuring the quality of outputs was recognised as a key focus area for a user-centric DW recovery process. Herein, the current study recognised that waste processors must direct their efforts towards ensuring the quality of incoming waste streams, minimising quality failures during processing, addressing quality issues post-sales, and engaging in research to enhance the quality of RCMs.

The intrinsic link between the quality of reprocessed materials and the initial quality of the waste materials received for reprocessing has been acknowledged in extant literature (Agrawal, Singh & Murtaza 2016; Chileshe, Jayasinghe & Rameezdeen 2019; Prakash et al. 2021). This link was affirmed through the current study, which recognised ensuring input quality as a requisite for developing superior-quality RCMs. However, ensuring input quality is complicated in the context of RLSCs since waste materials can originate from diverse sources and applications, making their quality highly uncertain (Agrawal, Singh & Murtaza 2015; Guarnieri, e Silva & Levino 2016; Hung Lau & Wang 2009). Consequently, waste processors are required to adopt effective measures to ensure that high-quality waste materials are received for reprocessing. In this regard, waste processors can establish teams to liaise with demolition contractors to inform them of waste acceptance criteria and the undesirable materials that must be avoided. This proactive engagement ensures that demolition contractors supply waste materials of appropriate quality for processing, thereby mitigating inherent uncertainties with the quality of the inflows. Furthermore, applying a variable gate fee linked to the quality of the incoming waste materials can incentivise demolition contractors to supply cleaner, pre-sorted waste loads that can be

processed into high-quality outputs. This approach corresponds with the findings of Bao et al. (2023), who observed that staged charging schemes implemented by waste processors in China have improved their potential to receive waste streams of higher quality. It is crucial, however, to ensure that the gate fee is maintained below the landfill levy to encourage demolition contractors to divert their waste to MRFs instead of landfills. Owing to the high uncertainty regarding the quality of incoming waste materials, prior research has recognised the significance of waste processors thoroughly inspecting these materials before accepting them for reprocessing (Agrawal, Singh & Murtaza 2015; Fleischmann 2001). Aligned with this notion, the current study advocates for establishing multi-staged monitoring systems to control the influx of undesirable materials that can compromise the output quality. From a DW recovery perspective, special emphasis should be placed on detecting hazardous materials (e.g., asbestos), given their potential to pose serious health and safety risks to end users, consequently influencing waste processors' reputation in the industry.

Wijewickrama et al. (2021a) noted that the quality of an output depends on the quality of the processes adopted to produce that output. Aligned with this idea, the current study emphasised that waste processors must focus on minimising quality failures during processing to assure the quality of RCMs. To achieve this, waste processors must concentrate on processing and testing RCMs as per specifications since CPs consider the compliance of materials with such specifications as a prerequisite when selecting materials for construction projects (Gálvez-Martos et al. 2018). In order to ensure that the RCMs produced adhere to industry specifications, the waste recovery process must be configured accordingly. However, this is contingent upon the availability of specifications for RCMs, which are currently limited in the Australian context as recognised through the first phase of the study. With the absence of generic specifications for most RCMs, developing the ability to produce tailor-made outputs to meet the specifications of a specific project can also be a positive aspect to showcase the viability of RCMs, an aspect not recognised in prior research.

The current study highlighted the importance of undertaking periodic testing in adherence to testing requirements prescribed in specifications and standard Australian test methods through accredited laboratories. This resonates with the assertions of previous studies emphasising the crucial role of comprehensive testing in establishing the reliability of reprocessed materials, particularly given the potential for reprocessed materials to be contaminated with hazardous materials from their original uses (van der Vegt et al. 2022).

Adding to these studies, the current study recognised that periodic testing enables waste processors to identify and rectify process-related issues leading to quality failures, consequently reducing the likelihood of introducing sub-standard materials into the market. Additionally, the study identified a previously unhighlighted opportunity for waste processors to obtain pre-qualifications/accreditations for their RCMs. However, it is important to note that obtaining such pre-qualifications/accreditations can be limited by the generally lengthy and costly government pre-qualification/accreditation processes.

Even with the pre-acceptance monitoring of incoming waste, there is a risk that certain undesirable materials may pass through to subsequent processing stages, necessitating comprehensive material sorting and screening systems to capture such materials. Herein, the study findings highlighted the effectiveness of employing a combination of manual and automated systems to effectively capture all undesirable materials that can compromise the quality of RCMs. The need for such comprehensive sorting and screening systems has been recognised in RL literature (Agrawal, Singh & Murtaza 2015). Further, the findings emphasised the importance of waste processors directing their focus towards stockpile management to avoid cross-contamination. In line with Silva, de Brito and Dhir (2017), the current study concurred that distinct stockpiles for different categories of incoming waste and processed materials must be maintained to prevent cross-contamination. Interestingly, the findings identified innovative approaches such as aerial drone photography to accurately establish the locations of different stockpiles, simplifying visual identification for on-site employees. As part of stockpile management, the findings recognised the significance of establishing protocols to handle hazardous materials like asbestos, if identified within the stockpiles, to ensure that such materials are isolated and removed safely to minimise the risk of contamination. These requisites for hazardous material management align with established guidelines, including those for asbestos management, provided by bodies such as the EPA South Australia (Environment Protection Authority (EPA) South Australia 2017).

The high labour involvement in the DW recovery process increases the susceptibility of the process to human errors, which can subsequently affect the output quality. Therefore, waste processors must proactively adopt measures to mitigate such human errors to enhance output quality. This imperative of managing the ‘human’ facet in quality assurance has been recognised by Hassan (2010), who argued that the success of quality improvement programs could not be guaranteed unless employee involvement and commitment were taken care of. Consequently, the current study recognised upskilling

employees as a viable approach to minimise human errors in the waste recovery process and uphold output quality. Through training and capacity building, employees can be guided to follow correct work procedures, thereby minimising quality issues. The significance of training was affirmed by prior studies on RL, which have recognised the need for skilled personnel to boost RL activities (Govindan & Bouzon 2018; Hung Lau & Wang 2009). In particular, the shortfall of skilled labour in Australia has bolstered the need for such upskilling initiatives.

As part of minimising quality failures during processing, the current study revealed that waste processors can opt for third-party accreditation for their quality management systems (e.g., ISO 9001 certification) as a mechanism to ensure the consistency and reliability of their quality management practices and consequently, the quality of their outputs. This was supported by Hassan (2010), who recognised that quality can be integrated into organisational processes by implementing certifications such as ISO 9001. In the context of producing RCMs, such certifications could promote continuous quality improvements by requiring quality controls to be consistently applied, all quality-related activities to be documented, and periodic auditing of quality management practices to be carried out that allows for the identification of opportunities for improvement.

In addition to ensuring the quality of inputs and minimising quality failures during processing, the current study recognised that waste processors must also address quality issues that may arise post-sales as part of their efforts to assure the quality of RCMs. This entails establishing systems to capture feedback regarding the quality of RCMs, which can subsequently be used to identify process improvement opportunities. Interestingly, the use of such feedback mechanisms for process improvement in the domain of RL remains unexplored in extant literature. Moreover, the findings emphasised the potential for waste processors to actively engage in research to enhance the quality of RCMs. To this end, collaborations between waste processors, governmental and non-governmental bodies and universities were proposed. This aligns with the observations of Liu et al. (2020) and Wijayasundara, Mendis and Zhang (2013), who recognised the prospect of synergistic partnerships between waste processors and research institutions in developing high-quality RCMs. Moving further, the current study recognised that waste processors could also engage in trial projects in partnership with government bodies, allowing for a comprehensive evaluation of the quality of RCMs under real-world conditions. Moreover, waste processors can collaborate with suppliers of complementary materials (e.g., processors of RCAs with concrete suppliers) to explore opportunities for quality

improvement and higher-order uses for RCMs, creating a win-win situation for both parties.

6.4.4 Supply reliability for user-centric demolition waste recovery

Supply reliability was recognised as a key expectation of CPs for using RCMs. Therefore, a user-centric DW recovery process must be structured to ensure that CPs can consistently source sufficient quantities of RCMs. To achieve supply reliability, the current study recognised that waste processors need to direct their efforts towards ensuring the continuity of material inflows for processing, minimising bottlenecks in processing, and developing distribution capabilities.

As input resources, waste materials exhibit less homogeneity than virgin materials, as evidenced by the high variation in generation volumes, timing and sources (Fleischmann 2001; Hung Lau & Wang 2009). Due to this heterogeneity, RLSCs encounter a higher level of uncertainty with regard to sustaining a continuous inflow of waste materials for processing. Consequently, waste processors must take proactive measures to ensure continuity in waste inflows, which is important for ensuring a reliable supply of RCMs. One approach to achieve this is optimising the location of MRFs in proximity to metropolitan areas, coupled with their accessibility through well-developed road networks. Proximity to metropolitan areas increases the potential for receiving waste since they are the primary sources of DW. Additionally, this allows demolition contractors to transport waste materials conveniently and cost-effectively to MRFs instead of landfills, thus bolstering the ability of waste processors to secure continuous supplies of waste materials. These observations align with Silva, de Brito and Dhir (2017) and Ulubeyli, Kazaz and Arslan (2017), who recognised that sending waste to MRFs over landfills largely depends on its economic appeal, determined primarily by haulage distances.

Extant literature in the domain of RL acknowledges that heightened uncertainty linked to the inflow of waste materials for processing necessitates increased levels of coordination between waste processors and waste generators, which is vital to ensure smooth material flows between these entities (Agrawal, Singh & Murtaza 2015; Govindan & Bouzon 2018). This imperative for increased coordination is supported by the Transaction Cost Theory, which recognises that within business environments characterised by widespread uncertainties, such as RLSCs, improving coordination among supply chain stakeholders can help organisations mitigate the impact of uncertainties on business operations (Carter, CR & Ellram 1998; Williamson 1981). In the context of RLSCs for DW, the findings

revealed that waste processors could achieve effective coordination by establishing dedicated teams to liaise with demolition contractors. Additionally, strategic partnerships, periodic price-based agreements and project-level agreements could be used to achieve greater coordination between waste processors and demolition contractors. Such arrangements enable waste processors to ensure a continuous inflow of waste materials for reprocessing. Meanwhile, demolition contractors benefit from reduced gate fees and guidance and support in waste management practices, thus creating a mutually beneficial scenario for both parties. Waste processors could also utilise the gate fee strategically to ensure the continuity of waste inflows. By maintaining the gate fee below the landfill levy and adjusting it based on inflow conditions, waste processors can control the supply of waste materials. This resonates with the findings of Wijayasundara, Mendis and Zhang (2013), who suggested using the gate fee as an incentive for directing waste materials towards reprocessing.

While ensuring the continuity of material inflows, it is equally important for waste processors to minimise bottlenecks in processing that can limit their ability to maintain reliable supplies of RCMs. The current study revealed that waste processors must progressively invest in improving processing capacity to align with the demand for RCMs. Particular emphasis was placed on investing in state-of-the-art technologies that can enhance the efficiency of waste recovery processes and allow higher recovery rates to be achieved. This aligns with prior research by Šomplák et al. (2014) and Hossain, R et al. (2022), identifying the removal of process bottlenecks through investments in waste recovery infrastructure as pivotal for successful waste management schemes in domains like municipal solid waste and plastic waste management. Adding to these studies, the current study acknowledged the potential benefits of incorporating spare capacity to accommodate demand fluctuations – a strategy frequently highlighted in operations management literature to address demand fluctuations (Kyrö, Peltokorpi & Luoma-Halkola 2019). However, unutilised spare capacity can reduce operational efficiencies and increase costs and should, therefore, be considered cautiously.

Further to eliminating capacity constraints, the maintenance of buffer stocks was recognised as another measure that could be used to minimise processing bottlenecks. Buffer stocks serve to counter the effects of market fluctuations and process disruptions on maintaining a reliable supply of RCMs. Extant research acknowledges that the need for buffer stocks is exacerbated in the context of RLCSs owing to the higher uncertainty associated with waste inflows (Fleischmann 2001; Minner 2001). These studies recognised

the complexity of precise planning amidst such uncertainties and highlighted the efficacy of buffer stocks in mitigating the timing and quantity deviations in return flows, thereby fostering a continuous supply of reprocessed materials downstream. However, the current study recognised that the maintenance of buffer stocks could be subject to conditions stipulated in the operating licenses issued to MRFs and is also influenced by governmental reporting requirements, such as mass balance reporting in South Australia (Environment Protection Authority (EPA) South Australia 2023a). Such regulatory requirements curtail the accumulation of excessive waste materials at MRFs, a stipulation that must be observed to balance the benefits of buffer stocks while adhering to licensing and reporting obligations.

Similar to buffer stocks, waste processors can employ centralised stock management systems to address uncertainties associated with waste inflows and effectively balance the influx of waste materials and the outflow of RCMs. Maintaining this balance between inflows and outflows holds significant importance for optimising RL operations, as underscored by Fleischmann (2001) and Hung Lau and Wang (2009). By consolidating information about material inflows and outflows, such a centralised system offers a holistic view of material movement throughout the waste recovery process. This allows proactive measures to be taken promptly if any shortfalls in material flows are identified. Notably, prior studies from the domain of RL, such as those from return vehicle management, have acknowledged the importance of effective stock management systems in ensuring enhanced inventory stability and better market responsiveness (Tseng et al. 2019). Adopting such centralised stock management systems would allow waste processors to decrease their reliance on buffer stocks by replacing physical stocks with information. Maintaining buffer stocks presents challenges due to licensing and reporting obligations and spatial limitations, which can be mitigated through centralised stock management systems.

In addition to ensuring the continuity of material inflows for processing and minimising processing bottlenecks, waste processors must also focus on developing distribution capabilities to ensure a reliable supply of RCMs. Similar to ensuring the continuity of inflows, optimising the location of MRFs also enhances waste processors' distribution capabilities. This follows the assertions of Fleischmann (2001), who argued that the location of MRFs should be determined by considering both supply sources and customer locations. Strategically locating MRFs near metropolitan areas where most construction activity occurs enables efficient and on-time deliveries of RCMs instead of delivering

materials from distant locations. The significance of developing efficient distribution networks capable of fulfilling timely deliveries in line with strict project timelines was also recognised as a prerequisite for maintaining supply reliability. This involves securing access to distribution vehicles and operators through company ownership or third-party contracts, which can be mobilised to fulfil orders promptly. Additionally, investment in transport management systems, which incorporate technologies such as GPS, can further enhance the ability to schedule vehicle movements effectively. This facilitates timely order fulfilment, a measure commonly used in forward logistics to support effective logistics operations (Gayialis, Kechagias & Konstantakopoulos 2022).

6.5 Chapter summary

This chapter discussed the research findings, commencing with the factors limiting the uptake of RCMs among CPs. This was followed by a discussion of the strategies for promoting the uptake of RCMs among CPs. Finally, the key focus areas for developing a user-centric DW recovery process were discussed in detail. The next chapter concludes the thesis by summarising the research findings under the individual objectives, highlighting the study's contributions to knowledge, practical implications, and limitations, and offering recommendations for future research.

CHAPTER SEVEN: CONCLUSIONS

7.1 Introduction

This chapter concludes the research by revisiting the objectives and discussing the degree to which the objectives have been achieved through the current study. Initially, the chapter presents a summary of the research findings under each of the objectives. This is followed by an outline of the contributions of the study to the body of knowledge and practical implications. Finally, the limitations of the study are highlighted, along with the recommendations for future research.

7.2 Summary of research findings

The viability and success of reverse logistics supply chains for demolition waste (RLSCs for DW) rely heavily on the market uptake of reprocessed construction materials (RCMs). Despite this, the uptake of RCMs is limited in most countries, including Australia, thus undermining the effectiveness of RLSCs for DW. Consequently, the first phase of this study focused on exploring how the uptake of RCMs can be promoted among construction professionals (CPs), the key actors responsible for selecting materials for construction projects (refer to Section 2.8.2.2). This study viewed the uptake of RCMs as a pro-environmental behaviour (refer to Section 2.8). A literature review on pro-environmental behaviour indicated that promoting such behaviours necessitates identifying limiting factors and potential strategies to encourage them. Therefore, the study's first and second objectives were set to identify potential factors that limit the uptake of RCMs among CPs and explore potential strategies for promoting the uptake of RCMs among CPs, respectively. A qualitative survey approach, which involved semi-structured interviews with CPs from architectural, engineering, and contracting backgrounds, was adopted to achieve these two objectives (refer to Chapter 4).

Furthermore, prior studies have acknowledged that waste processors, who occupy a central position within RLSCs for DW, must structure DW recovery processes in a user-centric manner to meet the requirements of the end users of RCMs, who, in this context, are the

CPs responsible for material selection. Despite this recognised need for user-centricity, recent studies revealed a dearth of research in this area. Consequently, the second phase of the study focused on understanding how waste processors can structure DW recovery processes to meet the requirements of CPs. Herein, the third and fourth objectives of the study were set to suggest measures that can be used by waste processors for structuring DW recovery processes to meet the requirements of CPs and to develop and validate a best-practice framework for a user-centric DW recovery process, respectively. A case study approach, which involved undertaking case studies with three waste processing companies that produce recycled concrete aggregates (RCAs), which represent current industry best practices in DW recovery, was followed to achieve these two objectives, while expert interviews were used to validate the framework developed (refer to Chapter 5).

The following sections summarise and present the key findings related to the objectives.

7.2.1 Objective 1: To identify potential factors that limit the uptake of reprocessed construction materials among construction professionals through a qualitative survey

In accordance with the Attitude-Behaviour-Context (ABC) Theory, the current study revealed that a mix of personal and contextual factors can limit the uptake of RCMs among CPs (refer to Section 4.3). Drawing upon ABC Theory and its subsequent conceptualisations, the personal factors were further classified under three sub-categories: attitudinal factors, personal capabilities, and habits or routines (refer to Section 2.8.2.3). The inherent risk averseness among CPs, the limited concern for environmental credentials when selecting materials and the perceived inferior quality and perceived high cost of RCMs were recognised as attitudinal factors that can limit the uptake of RCMs among CPs. The findings revealed that CPs' aversion to risk often leads them to favour established virgin materials, thereby limiting the uptake of RCMs. The findings also indicated that environmental considerations are generally given lower importance during the material selection process compared to aspects such as cost and ease of access. Further, the deep-rooted negative perceptions regarding the quality of RCMs and the perception of higher costs associated with these materials act as limiting factors to their uptake. The study also found that shortfalls with the personal capabilities of CPs, including a lack of knowledge and skills required for using RCMs and the limited time available to consider RCMs during the material selection process, could limit the uptake of RCMs. Interestingly, the lack of knowledge and skills was found to be more pronounced among builders due to

a lack of training on sustainability concepts, while architects and engineers were recognised as more attuned to such notions. The findings underscored that tight project timelines limit the ability of CPs to evaluate RCMs upfront, which generally require more research compared to virgin alternatives. Lastly, the tendency among CPs to gravitate towards routinely used materials was also recognised as a potential limiting factor under the category of habits or routines.

Based on the study findings, the contextual factors limiting the uptake of RCMs were classified under six sub-categories: client-related, organisation-related, cost-related, quality-related, availability-related, and regulatory environment-related factors. In relation to client-related factors, the findings revealed that a lack of client interest in using RCMs could limit CPs from embracing such materials. Under organisation-related factors pertaining to design and construction organisations, the findings highlighted that the lack of organisational support in enabling the use of RCMs could limit CPs from considering these materials. Moving to cost-related factors, the study recognised that due to the imperative for CPs to adhere to client budgets and offer economically competitive solutions, the higher cost of RCMs compared to their virgin alternatives can also limit the uptake of such materials. The findings identified several quality-related factors that can limit CPs from considering RCMs. Firstly, the inferior quality of RCMs compared to virgin alternatives was acknowledged, potentially leading to higher wastage, increased material requirements, and rectifications, thereby escalating costs. Secondly, the findings revealed that there can be a higher inconsistency in the quality of RCMs compared to virgin alternatives. Thirdly, the lack of certifications or guarantees to ensure the quality of RCMs was noted, deterring CPs from considering these materials due to the potential risks associated with unverified quality. Lastly, the lack of traceability to previous uses was found to raise questions regarding the quality of RCMs, thus limiting their use. Furthermore, the difficulty in sourcing sufficient quantities of RCMs and inconsistencies in supply were recognised as availability-related factors that could limit the uptake of RCMs. Under regulatory environment-related factors, limitations with existing standards and specifications related to RCMs were identified, limiting CPs from determining the suitability of RCMs for specific applications. The study also found that the complexity and time-intensive nature of current approval processes posed hurdles in obtaining approvals for using RCMs.

7.2.2 Objective 2: To explore potential strategies for promoting the uptake of reprocessed construction materials among construction professionals through a qualitative survey

The current study identified a multitude of strategies that can be adopted to promote the uptake of RCMs among CPs (refer to Section 4.4). Drawing from the literature on pro-environmental behaviour, these strategies were classified broadly into two categories: informational and structural (refer to Section 2.8.2.4). Informational strategies focus on changing the attitudinal factors that limit the uptake of RCMs, while structural strategies aim to change the contextual factors and habits or routines limiting the uptake. The identified strategies were also mapped against the stakeholders responsible for implementing them (refer to Section 4.4.4).

According to the literature review, the informational strategies were divided into five sub-categories: information and education, modelling, commitment, feedback, and credibility-building (refer to Section 4.4.1). The findings revealed six strategies within the sub-category of information and education. First, external experts like ESD Consultants can be brought into design and construction teams to guide CPs on using RCMs based on their expertise in sustainable construction practices. Secondly, sustainability forums can be set up at the level of design and construction organisations to share knowledge about sustainability initiatives, including using RCMs. The third strategy entails improving the marketing of RCMs, whereby waste processors are encouraged to improve their marketing efforts to capture the attention of CPs and promptly provide the required information for selecting RCMs. Fourthly, educating students in AEC programs on using RCMs as part of curricula was recognised, thereby laying the foundation for them to expand their knowledge later through practice. The fifth strategy highlighted awareness-building initiatives undertaken by government bodies, local councils, sustainability organisations and professional institutes. Such initiatives can include forums for knowledge sharing, developing guidance materials, and offering specialist advice, collectively contributing to raising awareness among CPs regarding RCMs and the importance of considering alternative environmental-friendly material options. As the sixth strategy, developing a centralised database for RCMs was proposed, which could provide comprehensive information about RCMs, including their availability, costs, supplier details and locations, testing results and environmental data, making it convenient for CPs to access reliable information regarding RCMs. Modelling the use of RCMs through reference projects, a strategy to be undertaken by governmental bodies and sustainability organisations, was

recognised under the sub-category of modelling strategies. This strategy serves to demonstrate the practical applications and benefits of RCMs, thereby encouraging CPs to adopt similar methodologies. Under commitment strategies, the current study acknowledged the possibility of encouraging CPs to make written public commitments to incorporate RCMs into construction projects. Such an approach increases the likelihood of translating these commitments into tangible actions, thereby increasing the uptake of RCMs. Developing tools to provide feedback on the positive environmental impacts of using RCMs was recognised as a feedback strategy enabling CPs to see the environmental benefits of using RCMs over virgin materials and prompting them to consider RCMs during material selection. Lastly, strengthening the credibility of RCMs by providing information through trusted sources was recognised as an informational strategy for promoting the uptake of RCMs.

Based on the literature review, the structural strategies were divided into two sub-categories: infrastructural and legislative and policy (refer to Section 4.4.2). Five strategies were identified under the sub-category of infrastructural strategies. Firstly, embedding sustainable material use as a priority consideration in the methodology of design and construction organisations was suggested, prompting CPs to consider RCMs during material selection and engaging clients in discussions about their feasibility. Secondly, the need for waste processors to improve the cost-competitiveness of RCMs was emphasised, considering the fact that RCMs are generally more expensive than virgin alternatives. Thirdly, improving and assuring the quality of RCMs was recognised as a pivotal aspect, necessitating waste processors to adopt better quality control measures, testing regimes, and certifications to ensure that RCMs meet or exceed the quality of virgin materials. Ensuring reliable supplies of RCMs was recognised as the fourth strategy, which emphasised the importance of waste processors ensuring that sufficient quantities of RCMs could be sourced consistently. As the fifth strategy, developing systems to trace RCMs to their previous uses was proposed to address quality concerns stemming from previous questionable uses of RCMs and to meet sustainability rating requirements. This was recognised as a strategy to be implemented by waste processors and could incorporate technological solutions like BIM, digital twins and RFID to enhance traceability. Five strategies were also identified under the sub-category of legislative and policy strategies. Firstly, the significance of developing standards and specifications for RCMs was recognised to facilitate their widespread use. Secondly, the possibility of using incentives to drive the uptake of RCMs was acknowledged, which can be done by either incentivising

the use of RCMs in government projects or using pricing policies that make RCMs more economically attractive compared to virgin alternatives. Thirdly, the findings recognised imposing mandates that require RCMs to be considered when making decisions around materiality as a potential avenue for promoting the uptake of RCMs among CPs. Fourthly, the importance of providing a clear pathway for obtaining approvals for RCMs not covered by current specifications was emphasised. The four strategies mentioned above should be executed at the governmental level. Lastly, as the fifth strategy, allocating higher credits for using RCMs in sustainability rating tools was noted, which is a strategy to be implemented by sustainability rating organisations.

7.2.3 Objective 3: To suggest measures that can be taken by waste processors for structuring demolition waste recovery processes in a user-centric manner to meet the requirements of construction professionals through case studies

Drawing from the first phase of the study that identified potential strategies for promoting the uptake of RCMs among CPs, five focus areas were identified that should receive the attention of waste processors when structuring DW recovery processes in a user-centric manner to meet the requirements of CPs. These included (1) effective marketing of RCMs, (2) enhancing the cost-competitiveness of RCMs, (3) assuring the quality of RCMs, (4) ensuring reliable supplies of RCMs, and (5) traceability of RCMs to prior uses. Consequently, under the second phase of the study, the measures taken by waste processors to achieve these five focus areas were explored using case studies.

The findings revealed that waste processors can adopt various measures to improve their marketing efforts, which can be classified into three broader categories: physical channels, electronic channels, and printed channels (refer to Section 5.5.1 and Table 5.7). Under physical channels, establishing dedicated sales teams for one-to-one marketing was recognised as a primary approach, considering the relationship-based nature of material sourcing in the construction industry. Apart from such teams, other physical channels, including participation in conferences, trade expos, and industry forums, undertaking awareness programs, and providing opportunities for site visits, can also be considered by waste processors to market their materials in a more personalised and interactive manner. In conjunction with physical marketing channels, waste processors can also adopt diverse electronic marketing channels, including websites, social media platforms, online newsletters, and external online platforms. Particularly, the use of social media platforms surfaced as an emergent approach, supported by the growth of social media as an effective marketing tool. Alternatively, the potential for using external online platforms was found

to be limited due to the limited availability of such platforms. Further, the findings revealed that while printed channels, such as brochures and trade publications, remain viable options, they may not align well with the sustainability ethos generally upheld by waste processors.

To improve the cost competitiveness of RCMs, the findings revealed that waste processors must manage three cost categories: capital costs, processing costs, and distribution costs (refer to Section 5.5.2 and Table 5.9). Setting up MRFs requires a high capital investment, and this capital cost can be managed through the pursuit of economies of scale. However, a cautious approach should be followed in pursuing economies of scale, which could otherwise result in the maintenance of excessive redundant capacity. In terms of managing processing costs, automation was identified as a possible approach due to the high labour costs stemming from the labour-intensive nature of DW recovery processes. Furthermore, a variable gate fee based on waste quality proved to be effective in offsetting processing costs and sustaining competitive pricing. Equally significant is managing distribution costs, which can be achieved through optimising facility locations in proximity to demand hubs and developing efficient distribution networks, thereby streamlining order fulfilment while minimising vehicular movements.

The findings emphasised that to improve and assure the quality of RCMs, waste processors need to focus on ensuring input quality, minimising quality failures in processing, and resolving post-sales quality issues (refer to Section 5.5.3 and Table 5.10). To ensure input quality, waste processors can establish teams to liaise with demolition contractors, advising them on waste acceptance criteria and undesirable materials that must be avoided. Further, a quality-based variable gate fee structure can be adopted to incentivise demolition contractors to pre-sort DW, resulting in the receipt of cleaner waste streams. Comprehensive input monitoring systems can also be employed to scrutinise incoming waste for quality issues. To minimise quality failures in processing, focus should be given to processing and testing materials as per specifications. Comprehensive sorting and screening systems can also be deployed to remove undesirable materials that can compromise the quality of the output. Further, effective stockpile management can prevent cross-contamination during storage, while upskilling employees can help minimise quality failures from materialising. Waste processors can also opt for third-party accreditations like ISO 9001 to promote continuous quality improvements. Establishing feedback mechanisms can aid in resolving post-sales quality issues, whereby the feedback received

can be used to identify process improvement opportunities. Furthermore, waste processors can consider product research initiatives to improve the overall quality of their outputs.

To ensure a reliable supply of RCMs, waste processors must focus on ensuring continuity of inflows, minimising bottlenecks in processing, and improving distribution capabilities (refer to Section 5.5.4 and Table 5.11). Continuity of inflows can be achieved by optimising the location of MRFs close to metropolitan areas with high construction activity, thereby providing improved access to DW. Dedicated teams can also be established to liaise with demolition contractors and negotiate access to waste materials. Vertical integration arrangements, such as strategic partnerships and agreements, can be pursued to further secure access to waste materials. The strategic management of the gate fee also presents an avenue to ensure the continuity of waste inflows for processing. To minimise processing bottlenecks, waste processors can explore opportunities to improve processing capacity, maintain surplus capacity and establish buffer stocks to mitigate supply fluctuations. Centralised stock management systems can also be used to monitor material inflows and outflows closely to maintain an equilibrium between the two flows. As part of improving distribution capabilities, waste processors can consider optimising the location of MRFs, developing efficient distribution networks, and incorporating advanced transport management systems.

Although tracking RCMs to their previous uses was identified as a focus area, the findings did not reveal any measures that waste processors can use to track the materials to their previous uses. This mirrored the findings from the first phase, which noted that sophisticated material tracking systems are not currently used in the DW recovery industry.

7.2.4 Objective 4: To develop a best-practice framework for a user-centric demolition waste recovery process and validate it through expert interviews

By collating the measures taken by the case study companies in structuring their processes to meet the requirements of CPs, as ascertained through the case studies conducted during the second phase of the study, a best practice framework was developed for a user-centric DW recovery process. This framework, depicted in Figure 5.17, focuses on four of the five focus areas that should receive the attention of waste processors when structuring their processes in a user-centric manner to meet CPs' requirements. Tracking RCMs to their prior uses, one of the focus areas, had to be omitted from the framework since no supporting measures on how waste processors could track RCMs to their previous uses were identified. The framework systematically presents the measures that waste processors

can take to achieve the focus areas, while a supplementary document was developed to be used alongside the framework, which explains the specific measures in greater detail. The framework was also validated for its practicality through expert interviews.

7.3 Contributions to knowledge

According to Phillips and Johnson (2022, p. 77), a Ph.D. research could be considered original if it complies with, but is not limited to, the following elements: (1) looking at areas that people in the discipline have not previously looked at; (2) making a synthesis that has not previously been made; and (3) carrying out empirical work that has not previously been done. The following sections explain the knowledge contributions of this research under these elements.

7.3.1 Looking at areas that people in the discipline have not previously looked at

Previous research has demonstrated that the success of RLSCs for DW relies heavily on the market uptake of RCMs. For instance, Yu et al. (2021) noted that successful RL requires more than the mere collection and reprocessing of waste materials and that it needs to be complemented by a well-developed consumption process. Such studies have argued that neglecting the consumption or market aspect of RL could undermine the long-term viability of RLSC operations. However, as explained under Section 2.7, the uptake of RCMs remains limited in many countries, including Australia, and there exists a gap in research regarding promoting the uptake of RCMs among end users. The current study endeavoured to bridge this knowledge gap by undertaking a qualitative survey to explore the limiting factors and strategies to promote the uptake of RCMs from the perspective of CPs, who are the key actors responsible for material selection in construction projects. Despite a few studies identifying certain limiting factors and improvement strategies for the uptake of RCMs in other contexts such as UK and China (Ding, Nie & Wu 2022; Oyedele, Ajayi & Kadiri 2014), to the best knowledge of the author, the current study is among the first to comprehensively explore the uptake of RCMs from the perspective of CPs in the Australian construction industry, thus making a notable contribution to the existing body of knowledge.

Prior research has recognised the importance of waste processors structuring DW recovery processes in a user-centric manner to meet the requirements of the end users of RCMs (Jayasinghe, Chileshe & Rameezdeen 2019; Liu et al. 2020; Tennakoon, Rameezdeen & Chileshe 2022b; Yeheyis et al. 2013). Despite the need for such a user-centric approach being acknowledged, a noticeable knowledge gap exists within this domain, as noted in

Section 2.9.2. This study effectively addressed this knowledge gap by conducting in-depth case studies with waste processors engaged in producing RCAs from DW – a prevailing industry best practice. The case studies explored how these waste processors have structured the DW recovery process to meet the requirements of CPs. Following this, a best-practice framework was developed and validated, which could be used by waste processors to structure DW recovery processes in a user-centric manner. While multiple studies have been conducted specifically focusing on the RLSCs for DW (Jayasinghe, Rameezdeen & Chileshe 2022; Wijewickrama et al. 2022a), to the best of the author's knowledge, this study is the first to explore how waste processors can structure the DW recovery process in a user-centric manner, thus making a significant contribution to the existing knowledge base.

This study makes a noteworthy contribution to knowledge through its efforts to address previously overlooked knowledge gaps, as explained in the above paragraphs. This aligns with the perspectives of Brown and Dant (2008) and Summers (2001), who recognised filling gaps in existing knowledge as a means by which research can contribute significantly to the existing body of knowledge.

7.3.2 Making a synthesis that has not previously been made

The current study looked at the uptake of RCMs from the perspective of pro-environmental behaviour, a previously unexplored synthesis of two distinct domains. The study incorporated literature from the domain of pro-environmental behaviour, including ABC Theory and literature on behaviour change strategies, which were used as theoretical frameworks to explore the uptake of RCMs. The ABC Theory provided a useful framework for identifying and categorising factors that could limit the uptake of RCMs among CPs engaged in material selection decisions. Similarly, literature on strategies for promoting pro-environmental behaviours was used to facilitate identifying and categorising strategies aimed at promoting the uptake of RCMs. The use of these theoretical frameworks helped to capture the broader themes that should be explored through the study, specifically in relation to the potential factors that would affect the decision of CPs whether to select RCMs or not and the potential strategies to overcome any hesitancy around the use of such materials. This study empirically demonstrated that such theoretical frameworks can be employed effectively to gain insights into the uptake of RCMs among CPs, thereby extending their scope into the construction domain. The predictive power of these theoretical frameworks was clearly evident from the study findings, which aligned closely with constructs from ABC Theory and pro-environmental

behaviour. The findings indicated that in accordance with predictions from ABC Theory and its subsequent refinements, both personal factors (i.e., attitudes, personal capabilities and habits or routines of CPs) and contextual factors (i.e., client-related, organisation-related, cost-related, quality-related, availability-related, and regulatory environment-related) can act as limiting factors for the uptake of RCMs among CPs. Likewise, in line with the literature on pro-environmental behaviour, the findings underscored the importance of employing a combination of informational and structural strategies to promote the uptake of RCMs among CPs. It is important to note that without the incorporation of these theoretical perspectives at the outset of the study, there would have been a risk of failing to comprehensively capture the limiting factors and strategies for promoting the uptake of RCMs among CPs. For example, the study might have focused solely on contextual factors influencing CPs' decisions to select RCMs, neglecting the critical consideration of personal factors in the decision-making process or vice versa.

According to Brown and Dant (2008), the use of theoretical frameworks from the domain of pro-environmental behaviour to explore the uptake of RCMs represents a notable theoretical contribution of this study, given that it involves the application of new theories to existing issues, a key avenue through which a study could make knowledge contributions. According to prior literature, theoretical frameworks from the domain of pro-environmental behaviour have been used to explain pro-environmental behaviours related to environmentally conscious purchasing, energy consumption, household recycling, sustainable transportation, and sustainable tourism. However, they have rarely been used in areas related to construction, specifically with regard to reverse logistics for demolition waste. Therefore, the use of theoretical frameworks from the domain of pro-environmental behaviour to explore the uptake of RCMs presents a notable theoretical contribution of this study. It should also be noted that these theoretical frameworks generally comprise of high-level constructs. For instance, these theoretical frameworks indicate that contextual factors can influence PEBs but does not indicate what are the specific contextual factors that apply to a given PEB. Consequently, the current study made further knowledge contributions by delving deeper to understand how these high-level constructs apply to the specific PEB of the uptake of RCMs among CPs.

Furthermore, while the need for adopting a user-centric approach to RL has been acknowledged in prior literature (Ahmadi et al. 2022; Carter, CR & Ellram 1998; Dowlatshahi 2000; Shokouhyar, Dehkhodaei & Amiri 2022), the concept had not been looked at previously from the perspective of RLSCs for DW. The current study is among

the first to introduce the concept of user-centricity, which advocates for business processes to be aligned with end-user requirements, to the domain of RLSCs for DW. By integrating these two domains, the current study makes a synthesis that has not previously been made. Herein, the study identified key focus areas that warrant the attention of waste processors in RLSCs for DW when structuring their processes in a user-centric manner. Further, the measures waste processors could adopt to achieve the focus areas were also proposed and developed into a framework as elaborated in Chapter 5. In doing so, this study integrated two separate areas of inquiry that had not been looked at together previously.

7.3.3 Carrying out empirical work that has not previously been done

Although literature reviews have been conducted on topics related to the uptake of RCMs, which have referred to certain limiting factors and improvement strategies (Caldera, Ryley & Zatyko 2020; Tennakoon, Rameezdeen & Chileshe 2022a), such findings have not been explored empirically, particularly in the Australian context from the perspective of CPs involved in material selection. Consequently, this study makes a notable contribution to knowledge by empirically investigating the limiting factors and strategies for promoting the uptake of RCMs from the perspective of CPs in the Australian context. Further, to the author's best knowledge, this is the first study to empirically explore the uptake of RCMs through a theoretical perspective of pro-environmental behaviour. Despite few studies identifying certain limiting factors and improvement strategies for the uptake of RCMs in contexts such as the UK and China (Ding, Nie & Wu 2022; Oyedele, Ajayi & Kadiri 2014), such studies have followed quantitative approaches with minimum descriptions of such aspects. In contrast, by employing a qualitative survey approach, this study delved deeper into the limiting factors and strategies to provide a more nuanced understanding.

Furthermore, although the need for user-centricity in RLSCs for DW has been acknowledged in extant literature (Jayasinghe, Chileshe & Rameezdeen 2019; Liu et al. 2020; Tennakoon, Rameezdeen & Chileshe 2022b), no empirical studies have explored how waste processors can structure their processes in a user-centric manner to meet the requirements of CPs. To the author’s best knowledge, this is the first study to empirically explore this knowledge gap, facilitated by conducting case studies involving waste processors engaged in producing RCAs from DW– a prevailing industry best practice.

7.4 Practical implications

In addition to the contributions to knowledge discussed above, many notable implications for the professional practice of different stakeholders of the RLSC for DW could be proposed based on the findings from this study.

The most notable among them is the best-practice framework for a user-centric DW recovery process (refer to Figure 5.17), which was developed targeting waste processors, who play a crucial role in RLSCs for DW. The framework provides useful guidance for waste processors to structure DW recovery processes in a user-centric manner to effectively meet the requirements of CPs involved in material selection for construction projects. As substantiated through the literature review, following such a user-centric approach to DW recovery would enhance user satisfaction, subsequently encouraging a wider uptake of RCMs (Ahmadi et al. 2022; Shokouhyar, Dehkhodaei & Amiri 2022; Tennakoon, Rameezdeen & Chileshe 2022a). The framework highlights four focus areas that should be considered by waste processors when structuring DW recovery processes in a user-centric manner. These include (1) effective marketing of RCMs, (2) enhancing the cost-competitiveness of RCMs, (3) assuring the quality of RCMs, and (4) ensuring reliable supplies of RCMs (a fifth focus area – traceability of RCMs to prior uses – had to be omitted from the framework since the study findings did not reveal any measures that could be used to track RCMs to their previous uses). The framework systematically presents actionable measures waste processors can take to achieve these four focus areas. A supplementary document was developed alongside the framework, which offers detailed explanations of the individual measures, thereby facilitating waste processors to implement these measures in practice. Importantly, the framework's practical applicability was also evaluated through the study, thus confirming its suitability for use in practice. As Dale et al. (2019) highlighted, frameworks, which are basic structures that underlie a system or concept, play a vital role in bridging the gap between knowledge and practice. Aligned with this perspective, it can be contended that the best-practice framework for a user-centric DW recovery process developed in this study makes a notable contribution to bridging the divide between knowledge and practice. The imperative for developing a stronger synergy between RL knowledge and practice was affirmed by Wilson and Goffnett (2022), who noted that despite the growing body of literature on RL, there is limited support for organisations to understand how this theoretical knowledge can be translated into practice. Following the categorisation of frameworks proposed by Dale et al. (2019), which classifies frameworks as theoretical, conceptual, or management-

oriented, the framework developed in this study falls within the category of management frameworks since it includes a specific set of measures that could be followed to achieve a specific outcome.

The study also highlighted several practical implications for government involvement in promoting the uptake of RCMs among CPs. One aspect pertains to the government's responsibility in raising awareness among CPs about RCMs and the significance of considering such alternative material solutions. This can be supplemented by developing a centralised database for RCMs, which would streamline access to information about RCMs offered by different suppliers. Leveraging its role as a client in numerous construction projects, the government can promote the uptake of RCMs by incorporating such materials into their projects, effectively demonstrating their practical applications. Similarly, government endorsement and support for research endeavours regarding RCMs can strengthen their credibility. The government can also focus on developing tools to provide feedback on the positive environmental impacts of using RCMs, thus providing insights into the environmental benefits of opting for RCMs over virgin alternatives. The government's role equally extends to formulating tailored standards and specifications for RCMs, and it can also consider incentivising or mandating the use of RCMs, albeit with caution in cases where supply is limited. Finally, the study recognised that the government could also consider streamlining approval procedures for RCMs in promoting the uptake of RCMs.

The study also identified several practical implications for interest aggregators, including educational institutes and non-governmental bodies, in promoting the uptake of RCMs. Herein, educational institutes are advised to prioritise integrating RCM-related knowledge into curricula, particularly for builders, who tend to possess less awareness of such concepts when compared to architects and engineers. Educational institutes can also strengthen the credibility of RCMs through dedicated research efforts. Non-governmental bodies, which include entities such as sustainability-rating bodies and professional institutes, also hold the potential to promote the uptake of RCMs by conducting CPD sessions targeting the use of RCMs, establishing knowledge-sharing forums, and developing guidance materials to build awareness regarding RCMs. Echoing the governmental role, non-governmental bodies can strengthen the credibility of RCMs by endorsing such materials and supporting research in this domain. They can also contribute towards developing a centralised RCM database and tools to provide feedback on the positive environmental impacts of using RCMs. Specifically, sustainability-rating bodies

can promote the uptake of RCMs by allocating higher credits for using RCMs in sustainability rating tools and providing examples of past projects that have successfully used RCMs. Moreover, professional institutes also possess a distinct ability to promote the uptake of RCMs by encouraging CPs to commit to using RCMs.

Although not explicitly identified as stakeholders within RLSCs for DW, the current study underscored the involvement of design and construction organisations in promoting the uptake of RCMs. This involvement includes the integration of external expertise, such as ESD Consultants, into design and construction teams, thereby encouraging and assisting CPs in embracing RCMs. Furthermore, establishing organisation-wide sustainability groups for disseminating knowledge about sustainability initiatives, including using RCMs, was emphasised. Moreover, the study proposed embedding sustainable material use as a priority consideration within the methodology of design and construction organisations, which could effectively encourage CPs to consider sustainable alternative materials such as RCMs.

7.5 Limitations and recommendations for future research

While the present study has made notable contributions to both knowledge and practice, as discussed above, it is important to note several inherent limitations of the study.

1. The scope of this study was limited to the Australian context. Therefore, future research can extend the findings of this study to the construction industries of other countries grappling with issues related to DW, resource scarcities and low uptake of RCMs. However, it is important to highlight that the contextual intricacies unique to each country must be weighed when seeking to extend these findings to a broader international context. This is particularly emphasised in the current research, which aptly acknowledged the influence of contextual factors on the uptake of RCMs. For instance, it must be reckoned that limitations with existing standards and specifications for RCMs – identified here as a notable contextual factor limiting the uptake of RCMs in the Australian context – might not be that pronounced as a limiting factor in certain European countries, such as the UK. In such contexts, where there are already actionable standards and specifications to support the use of RCMs, it would be futile to add more policies to promote the uptake of RCMs. Further, the framework developed under the second phase of the study was based on best practices in the Australian context. Therefore, not all measures identified for structuring DW recovery processes in a user-centric manner

may find equal resonance across different contexts. For instance, the potential for automating labour-intensive processes to alleviate processing costs might carry less relevance in countries where a surplus of labour is available at lower costs. Consequently, future research can be targeted to fit the framework to specific contextual conditions.

2. The focus of the study was also limited to analysing the RLSCs for DW and the RCMs derived from DW. This was because DW contributes to a greater proportion of all waste generated in the construction industry, making it prudent to prioritise the management of DW. However, it is worth noting that waste materials are generated throughout the entire life cycle of a construction project, including construction and renovation phases, and the characteristics and composition of such waste streams differ from those of DW. Hence, it would be valuable for future research to investigate the organisation of RLSCs for these alternative waste streams and explore the extent of market development for reprocessed materials originating from them.

3. The current study identified a range of strategies that could be adopted to promote the uptake of RCMs among CPs. However, these strategies could not be applied and evaluated for their effectiveness since they often require experimental research designs, which were not viable within the study's scope, funding, and timing constraints. Therefore, future studies could consider applying these strategies and evaluating their effectiveness to understand which strategies possess a greater potential to effectively address the factors limiting the uptake of RCMs among CPs.

4. Although tracking RCMs to their previous uses was recognised as a focus area that should receive the attention of waste processors when structuring DW recovery processes in a user-centric manner, the current study failed to identify any measures waste processors could adopt to achieve such traceability. Consequently, this aspect had to be omitted from the framework developed for a user-centric DW recovery process, which was recognised as a limitation of the current study. However, it is noteworthy that future technological advancements, such as digital twins and Radio-Frequency Identification (RFID), may offer the possibility for traceability of RCMs to their previous uses, potentially becoming a crucial component of any

waste recovery ecosystem and thus representing an area warranting further research.

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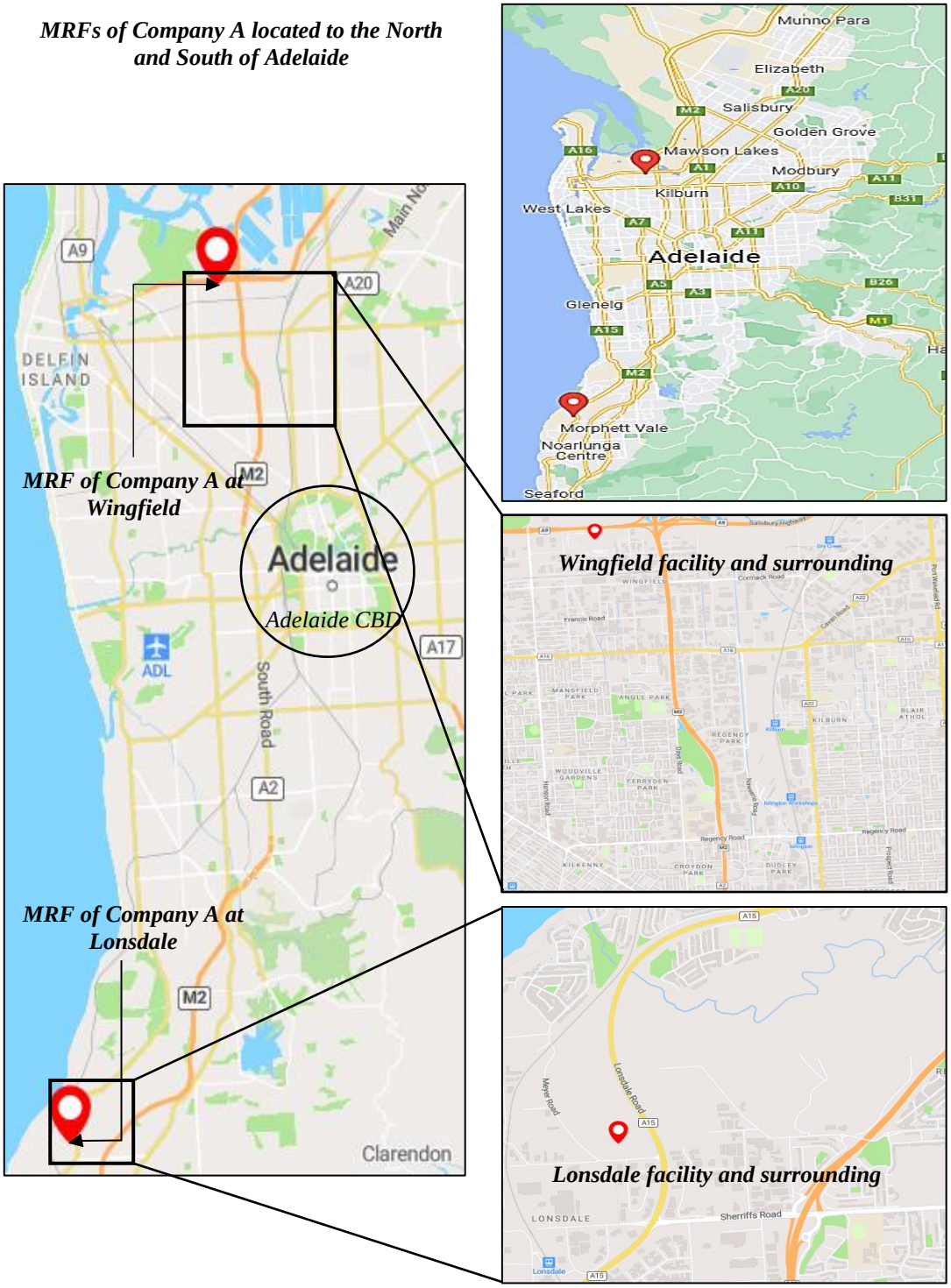
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APPENDICES

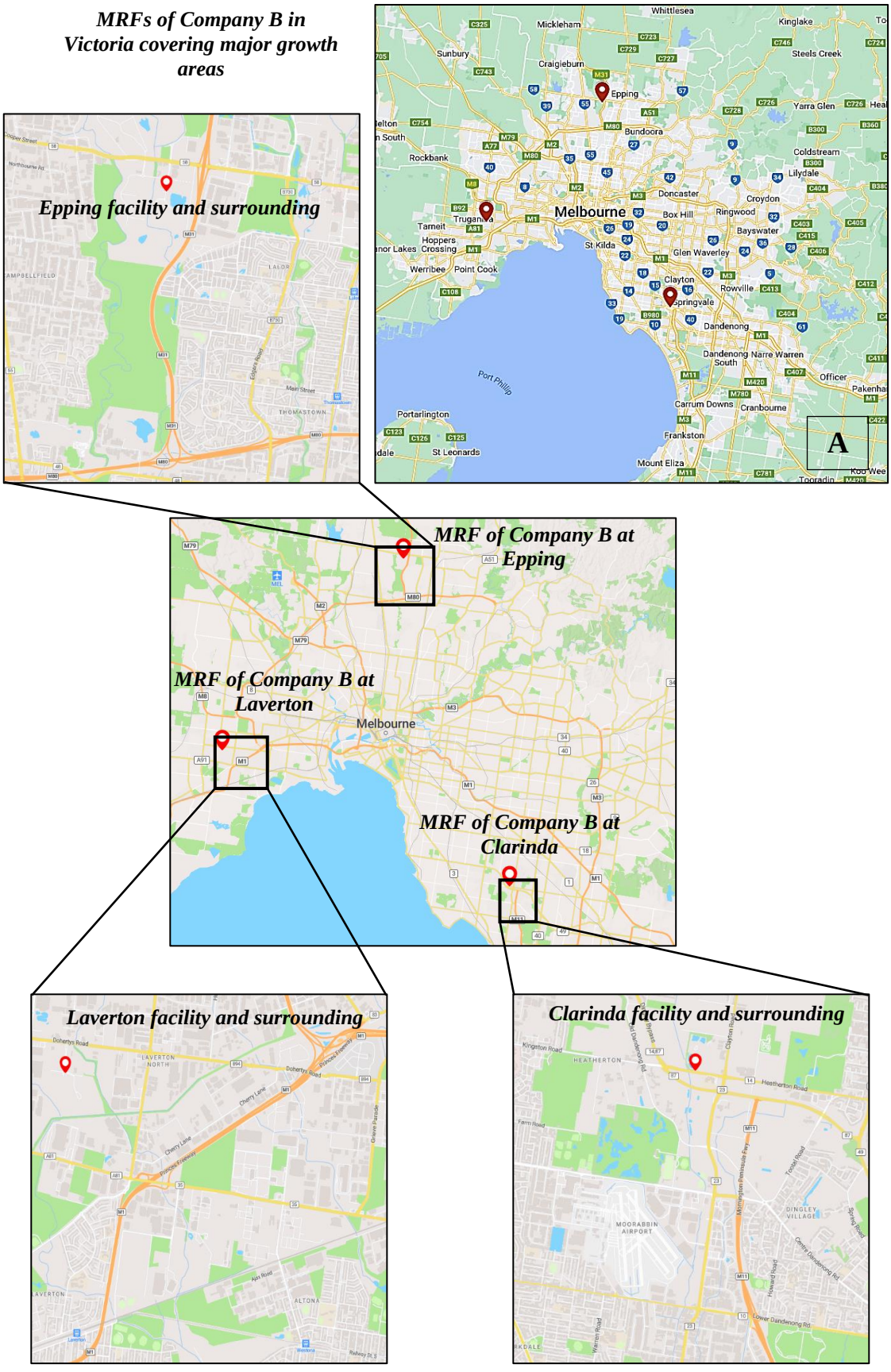
Appendix 1(A) – Location of material recovery facilities (MRFs) – Company A

MRFs of Company A located to the North and South of Adelaide



(Adapted from: Google Maps and Mapme.com)

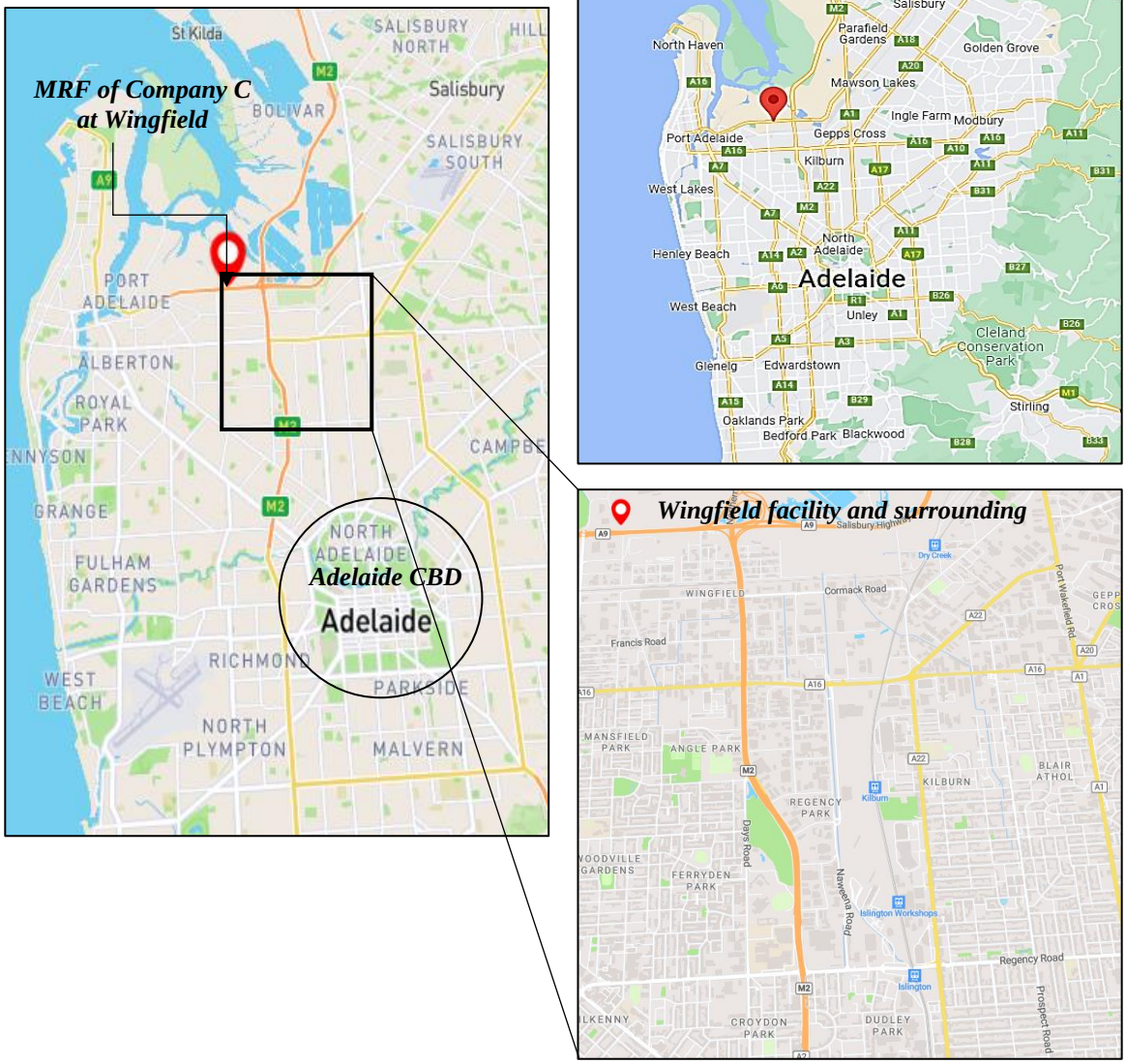
Appendix 1(B) – Location of material recovery facilities (MRFs) – Company B



(Source: Google Maps and Mapme.com)

Appendix 1(C) – Location of material recovery facility (MRF) – Company C

MRF of Company C located towards the populous northern suburbs of Adelaide



(Source: Google Maps and Mapme.com)

Appendix 2(A) - Qualitative survey: Interview guideline

Research Title: Towards circularity in construction: Promoting the uptake of reprocessed construction materials.

Researcher's use only

Code:	***Date:***
Duration:	***Venue:***

Section 1: Introductory questions

1. Can you provide a description of your current job role? What are your primary duties and responsibilities?

2. For how long have you been working in the field of construction?

3. Can you briefly elaborate on your experience with the use of reprocessed construction materials?

4. Can you recall examples of projects that you undertook that involved the use of reprocessed construction materials? [**Probes**: type of projects (residential, commercial, industrial etc.), type of reprocessed construction materials used, reasons behind the decision to use reprocessed construction materials.]

Section 2: Factors limiting the uptake of reprocessed construction materials among construction professionals

5. According to your understanding, what factors can limit the uptake of reprocessed construction materials among construction professionals? Can you elaborate with examples?

6. ***Attitudinal factors*** – Does the attitudes of construction professionals have an impact on the low uptake of reprocessed construction materials? If so, can you elaborate with examples? [**Probes**: intent to act pro-environmentally, non-environmental attitudes, perceived personal costs and benefits of action, specific beliefs/norms]

7. ***Personal capabilities*** – Do limitations with the personal capabilities of construction professionals have an impact on the low uptake of reprocessed construction materials? If so, can you elaborate with examples? [**Probes**: knowledge and skills, availability of time, economic resources]

8. ***Habits or routines*** – Do habits or routines of construction professionals have an impact on the low uptake of reprocessed construction professionals? If so, can you elaborate with examples?

9. ***Contextual factors*** – Do contextual factors have an impact on the low uptake of reprocessed construction materials among construction professionals? If so, can you elaborate with examples? [**Probes**: costs, quality, availability, legal and institutional factors]

Section 3: Strategies for promoting the uptake of reprocessed construction materials among construction professionals

10. According to your understanding, what potential strategies could be used to promote the uptake of reprocessed construction materials among construction professionals? Can you elaborate with examples and with reference to specific parties responsible for implementing them?
    Probes:
    a. ***Informational strategies*** [information and education, modelling, commitment, feedback, goal setting, credibility building strategies]
    b. ***Structural strategies*** [infrastructural, legislative and policy strategies]

Section 4: Concluding questions

11. Do you have any other insights that you would like to add regarding the factors limiting the uptake of reprocessed construction materials among construction professionals or strategies for promoting the use of such materials or about the use of reprocessed construction materials in general?

12. Can you suggest any other professionals from architectural, engineering, and contracting backgrounds with prior experience with reprocessed construction materials who can provide their input on my research?

Thank you!

Appendix 2(B) - Case studies: Interview guideline

Research Title: Towards circularity in construction: Promoting the uptake of reprocessed construction materials

Researcher's use only

Code:	***Date:***
Duration:	***Venue:***

Section 1: Introductory questions

1. Can you provide a brief description of your job role, what are your primary duties and responsibilities and for how long have you been working in the waste management sector?

2. Company details
    a. Can you provide a brief introduction about your company? [**Probes**: years of operation, facility locations, areas of operation]
    b. Can you provide an indication of the volume of demolition waste handled by your material recovery facilities per annum?
    c. How many employees are engaged in the process of demolition waste recovery?

3. Can you explain the process of waste recovery followed at your organisation from the point where the waste is received at your facility until it is reprocessed and sent to the market?

Section 2: In-depth investigation into the demolition waste recovery process

4. ***Marketing*** – Can you explain the measures that your company has taken to market your outputs to the end users? Please provide examples where possible [**Probes**: marketing channels used (physical, electronic); specifics of the information communicated; potential opportunities for further improving the marketing efforts]

5. ***Cost-competitiveness*** – Can you explain the measures that your company has taken to improve the cost-competitiveness of your outputs? Please provide examples where possible [**Probes**: main cost drivers and measures taken to manage such costs, measures taken to improve efficiency of the process, specific technologies used, potential opportunities to improve the cost-competitiveness of outputs further]

6. ***Improving and assuring quality*** – Can you explain the measures that your company has taken to improve and assure the quality of your outputs? Please provide examples where possible [**Probes**: reasons for quality failures and

measures taken to avoid such quality failures, quality control systems and procedures, testing regimes followed, quality certifications, mechanisms for addressing quality issues if identified, potential opportunities to further improve and assure the quality of outputs]

7. ***Supply reliability*** – Can you explain the measures that your company has taken to ensure reliability in the supply of your outputs? Please provide examples where possible [**Probes**: reasons for gaps in supply reliability and measures taken to address such gaps, mechanisms for ensuring a consistent supply of sufficient quantities, mechanisms for catering to demand fluctuations, potential opportunities to further improve supply reliability]

8. ***Traceability to previous uses*** – Can you explain the measures that your company has taken to trace your products to their previous usage? Please provide examples where possible [**Probes**: specific technologies (e.g., BIM, RFID) used, potential opportunities for further improving traceability to previous uses]

Section 3: Concluding questions

9. Do you have any other insights to add in terms of how your processes can be further improved to meet the requirements of the end users of your products?

10. Can you provide the following documentary resources (if available and possible)
    a. Annual reports
    b. Company policies and manuals (e.g., quality assurance)
    c. Documents outlining the waste recovery process
    d. Product brochures/ advertising materials
    e. Any other documents to support the areas of discussion

Thank you!

Appendix 2(C) - Validating the proposed framework for user-centric demolition waste recovery: Interview guideline

Research Title: Towards circularity in construction: Promoting the uptake of reprocessed construction materials

Researcher's use only

Code:	***Date:***
Duration:	***Venue:***

Section 1: Interviewee details

1. Background (Academia / Industry): _____
2. Designation: _____
3. Experience: _____

Section 2: Evaluation of the proposed framework

Question		Responses
1. What is your opinion about the structure and clarity of the framework? Is the framework understandable and user-friendly? • Overall presentation • Clarity of language used • Flow/Logic of elements presented in the framework		
2. What is your opinion about the level of coverage of the framework?	Overall (Main sections)	
	Section on "Effective marketing"	
	Section on "Enhancing cost-competitiveness"	
	Section on "Assuring quality"	
	Section on "Ensuring supply reliability"	
3. Do you have any further comments or recommendations regarding the proposed		

Question	Responses
framework – Any aspects that need to be included/deleted/improved within the framework?	
4. What is your opinion about the framework in terms of its usefulness in developing user-centric DW recovery processes? Would you recommend the framework to be used by waste processors to structure their processes in a user-centric manner?	

Thank you!

Appendix 3 – Statements of authorship for published works

University of South Australia

Statement of Authorship

Title of Paper	Diverting demolition waste toward secondary markets through integrated reverse logistics supply chains: A systematic literature review
Publication Status	☒ Published ☐ Accepted for Publication ☐ Submitted for Publication ☐ Unpublished and Unsubmitted work written in manuscript style
Publication Details Relevant reference details	Tennakoon, GA, Rameezdeen, R & Chileshe, N 2022, 'Diverting demolition waste toward secondary markets through integrated reverse logistics supply chains: A systematic literature review', Waste Management & Research, vol. 40, no. 3, pp. 274-93.
PRINCIPAL AUTHOR	
Name of Principal Author (Candidate)	Gihan Anuradha Tennakoon
Contribution to the Paper Brief description of your work in this publication	Gihan Anuradha Tennakoon is the major contributor to this research paper. He was responsible for undertaking the background study, reviewing the relevant literature, analysing and interpreting the findings, and drafting the research paper. Moreover, he was responsible for carrying out revisions to the paper based on reviewer comments.
Overall Percentage (%)	60%
Certification	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.
Signature *Signatures will be redacted by the Library at the time of publication*	[redacted] Date 5-Sep-23
CO-AUTHOR CONTRIBUTIONS	

By signing the Statement of Authorship, each author certifies that:

I. the candidate's stated contribution to the publication is accurate (as detailed above);

II. permission is granted for the candidate in include the publication in the thesis; and

III. the sum of all co-author contribution is equal to 100% less the candidate's stated contribution.

Name of Co-Author 1	Raufdeen Rameezdeen

% Contribution to the Paper	20%	
Signature *Signatures will be redacted by the Library at the time of publication*	[redacted]	Date: 10th September 2023
Name of Co-Author 2	Nicholas Chileshe	
% Contribution to the Paper	20%	
Signature *Signatures will be redacted by the Library at the time of publication*	[redacted]	Date: 10th September 2023

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Statement of Authorship

Title of Paper	Identifying factors affecting the low uptake of reprocessed construction materials: A systematic literature review
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Publication Details Relevant reference details	Tennakoon, GA, Rameezdeen, R & Chileshe, N 2022, 'Identifying factors affecting the low uptake of reprocessed construction materials: A systematic literature review', Waste Management & Research, vol. 41, no. 4, pp. 781-800.
PRINCIPAL AUTHOR	
Name of Principal Author (Candidate)	Gihan Anuradha Tennakoon
Contribution to the Paper Brief description of your work in this publication	Gihan Anuradha Tennakoon is the major contributor to this research paper. He was responsible for undertaking the background study, reviewing the relevant literature, analysing and interpreting the findings, and drafting the research paper. Moreover, he was responsible for carrying out revisions to the paper based on reviewer comments.
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% Contribution to the Paper	20%	
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University of South Australia

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Publication Details Relevant reference details	Tennakoon, GA, Rameezdeen, R & Chileshe, N 2023, 'Walking the talk towards sustainable consumption: interventions to promote the uptake of reprocessed construction materials', Engineering, Construction and Architectural Management, vol. ahead-of-print, no. ahead-of-print.
PRINCIPAL AUTHOR	
Name of Principal Author (Candidate)	Gihan Anuradha Tennakoon
Contribution to the Paper Brief description of your work in this publication	Gihan Anuradha Tennakoon is the major contributor to this research paper. He was responsible for undertaking the background study, reviewing the relevant literature, data collection and analysis and drafting the research paper. Moreover, he was responsible for carrying out revisions to the paper based on reviewer comments.
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Title of Paper	Why not reprocessed: identifying factors limiting the uptake of reprocessed structural timber
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Name of Principal Author (Candidate)	Gihan Anuradha Tennakoon
Contribution to the Paper Brief description of your work in this publication	Gihan Anuradha Tennakoon is the major contributor to this research paper. He was responsible for undertaking the background study, reviewing the relevant literature, data analysis and drafting the research paper. Moreover, he was responsible for carrying out revisions to the paper based on reviewer comments.
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University of South Australia

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Name of Principal Author (Candidate)	Gihan Anuradha Tennakoon
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