Circular economy in action: the application of products with recycled content in construction projects – a multiple case study approach

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Abstract

Purpose – The utilisation of products with recycled content (PwRC) in construction projects has been identified as a targeted way to achieve sustainable management of construction and demolition waste resources. However, sustainable applications of these resources are subject to a wide array of factors that demand a thorough investigation. This study, therefore, explores the motivations, barriers and strategies for optimal PwRC uptake using a multiple-case study approach.

Design/methodology/approach – This study adopted an interpretive multiple-case study approach. The case studies were selected from recently completed construction projects including two infrastructure projects, one commercial project and one residential project. A series of semi-structured interviews were carried out to collect the data. For each case study, four participants were interviewed; these participants represented design, client, supply and building teams.

Findings – The study revealed the main barriers, motivations and opportunities for adoption of PwRC resources in four construction projects. These factors are believed to influence the utilisation of PwRC to varying extents and/or in diverse ways. The findings also suggest that there is a significant opportunity for stakeholders to adopt more sustainable waste management practices, and the use of institutional drivers can help achieve this goal.

Research limitations/implications – The primary research contribution of the study lies in proposing three key research directions: investigating regulatory constraints impacting the use of PwRC, addressing supply chain challenges and enhancing quality assurance.

Originality/value – The research has a practical contribution to the industry through a suite of actionable strategies to increase the uptake of PwRC. The strategies are mostly focussed on stakeholders' education, the regulation that supports PwRC and project management planning. The two major motivations – referring to

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two of the three pillars of sustainability (economy and environment) – provide a basis for organisational changes to ensure achieving sustainability in construction activities.

Keywords Circular economy, Construction and demolition waste, Waste recycling, Decarbonisation, Residential, Commercial and infrastructure projects

Paper type Research paper

1. Introduction

The building and construction sector is known for its low level of resource efficiency (Kedir and Hall, 2021). As a result, the fast-paced construction activities in the sector bring about construction and demolition (C&D) waste in staggering quantities. Globally, nearly 100 billion tonnes of C&D waste are generated in the sector of which 35% is destined for landfills (United Nations Environment Programme, 2022). The utilisation of products with recycled content (PwRC) has been suggested as a way to sustainably manage these resources (Lu and Yuan, 2011; National Waste Policy, 2018). If planned properly, this management strategy will minimise waste disposal, keeping resources' value in the economy loop as long as possible and reducing the need for new material extractions.

From a theoretical perspective, several widespread initiatives such as the "circular economy", "waste hierarchy model", and "net-zero- (carbon) emissions" recommend using these resources. Particularly, PwRC uptake is widely promoted as an integral component of the circular economy and material circularity (Moraga *et al.*, 2019). Utilisation of PwRC contributes to resource conservation, waste reduction, energy savings, economic growth and the creation of closed-loop systems, while also promoting sustainability and environmentally responsible consumer choices. These contributions are established as key benchmarks or objectives for achieving circular economy goals in several prominent studies (Morseletto, 2020; Ghaffar *et al.*, 2020).

A few social science studies have explored the factors influencing the utilisation of these resources in construction projects. The findings suggest that the utilisation of PwRC is complex mainly because it is subject to a variety of internal and external factors that need to be well understood (Shooshtarian *et al.*, 2020a; Park and Tucker, 2017; Wijayasundara *et al.*, 2022). The current utilisation of PwRC in the building and construction sector is primarily limited to low-value applications (Di Maria *et al.*, 2018) otherwise known in waste management research as "downcycling". Previous research has identified reasons for the limitations of PwRC application including energy and transport costs, lack of knowledge, limited technologies, poor quality and contamination, lack of market, unproductive waste regulations and negative perceptions (Shooshtarian *et al.*, 2020a). The subsequent section explores the significance of the utilisation PwRC in the Australian context, followed by an overview of the research gap, aims and objectives.

2. Literature review

2.1 Australian context

In recent years there have been urgent calls for sustainable C&D waste management on the national level. Each state and territory has developed different waste management strategies and guidelines to address the growing issue of waste landfilling (Shooshtarian *et al.*, 2020b). Some argue that events such as the ban on waste export imposed by some countries (Shooshtarian *et al.*, 2021), increased construction activities in the infrastructure sector (Shooshtarian *et al.*, 2022f; Ratnasabapathy *et al.*, 2020) and COVID-19-related construction material supply shortages (Shooshtarian *et al.*, 2022a, b; Caldera *et al.*, 2022) have together influenced the advancement of the Australian waste management system.

As a result, recent statistics show that C&D waste management has improved in Australia. The Australian National Waste Report (Blue Environment, 2023) indicated that the rate of C&D waste recovery has reached 78% in 2020–2021, up 11% from the last reporting round (2018–2019). At the same time, the quantities of C&D wastes have increased by 39%, reaching 29 million tonnes in 2020–2021. This increase is primarily related to strong activities in major projects, particularly transport infrastructure developments (Blue Environment, 2023).

The increased waste recovery, however, has not necessarily been mirrored by an increased uptake of PwRC. Reports from the waste recovery industry show that some of these resources are stockpiled at waste recovery facilities in excess quantities (Active Sustainability, 2020; Victoria, 2021; ARRB, 2022). This trend presents many challenges for state governments, the waste recovery industry and the building and construction sector. It can negate the current efforts targeting circular economy application in the sector and attempts to close the loop for construction material lifecycles.

The utilisation of such stockpiled PwRC is subject to factors affecting the demand side, i.e. market development and stimulation. While previous research has investigated these factors in detail (Shooshtarian *et al.*, 2022a, b; King *et al.*, 2020; Ratnasabapathy *et al.*, 2021), the decision-making ecosystem for procuring PwRC, which is based on organisational motivations, challenges and mitigation strategies, is unclear.

2.2 Research gap, aim and objectives

To date, most of the research in this area only captures the overall experience of participants regarding the use of PwRC (Shooshtarian *et al.*, 2020a). Furthermore, many have a technical focus on the use of PwRC, limiting the opportunity to understand various contextual factors affecting their application. Hence, this study, by adopting a multiple case study approach, aims to bridge this gap to provide a realistic and up-to-date insight into the application of the PwRC in the Australian building and construction sector at the project level. The following objectives were formulated to achieve the main research aim:

(1) To identify the main challenges of using PwRC in construction projects

(2) To explore the main motivations for using PwRC in construction projects

(3) To investigate effective strategies to minimise the impact of challenges to using PwRC

The study is part of an extensive national study (Project 1.85 – Enhancing the use of products with recycled contents in the Australian construction industry). The findings of this study will guide government decision-makers and industry practitioners to facilitate the utilisation of PwRC and contribute to the further development of the circular economy in the building and construction sector.

3. Research methods

3.1 Research design

To achieve its research objectives, this study adopted an interpretive multiple-case study approach (Klein and Myers, 1999). This approach compares well to others in the spectrum of social science research methodology as it is considered suitable to provide an in-depth understanding of the complexities of the event within its context (Dul and Hak, 2007; Flyvbjerg, 2006). In recent years, the use of this approach has increased in the field of construction management, including the investigation of virtual reality (Almahmoud *et al.*, 2012; Ozcan-Deniz, 2019), the use of information technology in the construction industry

(Alshorafa and Ergen, 2021; Ahlam and Rahim, 2021), reverse logistics (Gustafsson and Bengtsson, 2020) and C&D waste management and circular economy (Çetin *et al.*, 2022; Adjei *et al.*, 2018; Rose and Stegemann, 2018).

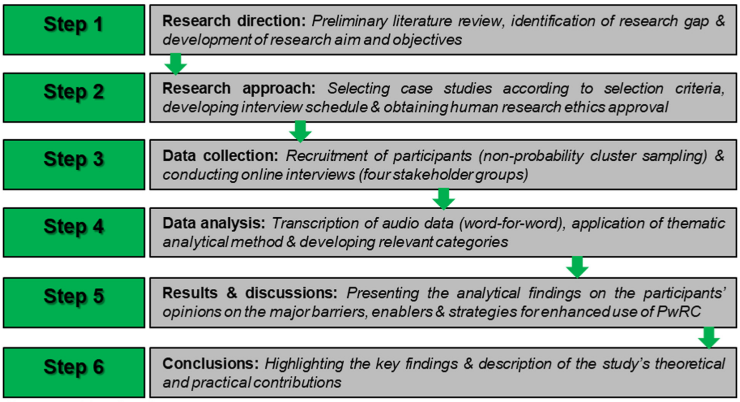
In most cases, the utilisation of PwRC is affected by complexities that need to be managed prior to, during and after the completion of construction projects (Purchase *et al.*, 2021). The case studies were selected from recently completed construction projects in two Australian states. The criteria for the selection of these case studies were: (1) the use of a significant quantity of PwRC; (2) reasonable access to the project information; and (3) the ability to recruit four research participants representing design, client, builder and supplier teams. The overall research process employed in this study is depicted in Figure 1.

3.2 Case setting and context

Four case studies were selected through a purposive sampling approach (Patton, 1990), based on criteria comprising functional and suitability attributes. Table 1 presents these attributes.

The case studies included two infrastructure (road transport) projects, one commercial project and one residential project. Except for one project (Burwood Brickworks Shopping Centre), all projects were government-owned projects.

The projects were built in two Australian states, Western Australia and Victoria, between 2018 and 2022 with budgets ranging from $2.7 M AUD to $400 M AUD. As shown in Table A1, the selected projects used significant quantities of PwRC in their construction activities. These projects have been recognised for outstanding levels of commitment to



Source(s): Authors

Figure 1.
Summary of the research process in this study

Functional attributes	Suitability attributes
1) The ability to recruit intended research participants from each selected project within the desired time frame 2) Reasonable access to the project information 3) Recent completion of the project	1) The use of a significant quantity of PwRC 2) The use of different types of PwRC 3) The representativeness of the three subsectors within the building and construction sector (commercial, residential and infrastructure) 4) Recognition for outstanding commitment to sustainability

Source(s): Authors

Table 1.
Case selection criteria

sustainability through different national sustainability recognition programs such as the Infrastructure Sustainability Council (ISC), Green Building Council of Australia (GBCA) and Urban Development Institute of Australia (UDIA). The projects have been referred to as demonstration projects for circular economy implementation on national and international levels (Plate 1).

3.3 Data collection and analysis

A series of semi-structured interviews were carried out to collect the data. The interviews were conducted online through Microsoft Teams between April 2022 and January 2023. In addition to questions related to the participants' demographic details, working experience and relevant expertise in the use of PwRC in construction projects, interviewees were asked about the main motivations, challenges and opportunities for the increased application of these materials in the selected case studies.

For each case study, four participants were interviewed; these participants represented design, client, supplying and building teams. Analysis of relevant literature (Shooshtarian *et al.*, 2020a; Ghaffar *et al.*, 2020; Zhao, 2021; Knoeri *et al.*, 2011; Bolden *et al.*, 2013) and consultation with experts representing public and private organisations (the project steering group members) helped the research team to select these four stakeholder groups as those believed to have a major role in using PwRC in construction projects.

Overall, 16 interviews were conducted before theoretical saturation was reached. The theoretical saturation point was considered to have been reached as no new themes were emerging from the interviews at this stage. The case studies were selected through a purposive (non-probability) sampling method based on criteria comprising functional and suitability attributes as outlined in Table 1. The study was undertaken according to the

Note(s): Top left: Brickworks Shopping Centre (commercial/Case Study; 1); Top right: Mordialloc Freeway (infrastructure/Case Study 2); Bottom left: Tonkin Gap Highway (infrastructure/Case Study 3); Bottom right: OneOneFive Hamilton Hill (residential/Case Study 4)

Source(s): In order of appearance from top left to bottom right: Armao (2021), Victoria's Big Build (2021), MainRoads Western Australia (2022) and TABEC (2022)

Plate 1.
Images of case studies

Australian National Statement on Ethical Conduct in Human Research (National Health and Medical Research Council, 2023) and the requirements of the RMIT University Human Research Ethics Committee. Piloting for interviews is a critical step to evaluate the questions and to obtain some practice in the interviewing process. To further guarantee the internal reliability of the study's interview questions, a series of pilot interviews were conducted between the research team and waste-related professionals. The feedback from the pilot interview assisted the research team to optimise the interview questions.

Audio data captured from the interviews were carefully transcribed by a professional transcriber word-for-word prior to the quality verification of text data by the research team. The transcripts were analysed using the NVivo Pro 12 application (Di Gregorio, 2000), which facilitates codifying text-based qualitative data. A deductive (theory-driven) coding system was initially adopted, using NVivo software, while new codes were created inductively from the interview data. The deductive codes were informed by the concepts established in previous literature on PwRC and sustainable ways to resources (Lu and Yuan, 2011; National Waste Policy, 2018).

A thematic analysis was applied to identify the emerging themes (Braun and Clarke, 2006) that were related to the three research objectives. Three coders were involved in the thematic analysis to achieve 80% inter-coder reliability. Furthermore, to better understand the qualitative data, a descriptive analysis of the data was undertaken. The main approach for these comparisons was frequency distributions of various categories of identified themes in the interviews. The constant comparative method (whereby interpretations and emergent findings are compared with existing findings) was employed to corroborate the interview findings (Fram, 2013).

3.4 Credibility and corroboration of findings

This study employed an interpretive approach, which means that the analysis may be subjective and emerging in nature. To ensure the validity of this approach, four guidelines that were developed by other scholars were followed. Firstly, a clear chain of evidence was provided (Walsham, 1995). Secondly, alternative explanations, multiple perspectives and potential biases were taken into account (Klein and Myers, 1999). Thirdly, the findings were corroborated, and the theoretical saturation point was reached (Strauss *et al.*, 1996). Finally, an effort was made to generalise beyond the area under investigation (Klein and Myers, 1999).

4. Results

4.1 Research participants profile

Table 2 summarises the profiles of the research participants, including their construction and waste recovery industry experience and knowledge. The majority of participants were substantially involved in the projects, allowing them to provide valuable information on the application of PwRC in the respective case study.

4.2 Barriers to using PwRC

The research participants reported 69 factors that influence the barriers towards the broad application of PwRC in the selected case studies (Figure 2a). The two stakeholder groups that provided the largest number of barrier factors in their responses to this question were designers and builders.

To better analyse these factors, they were organised into 11 categories through a thematic analysis. In three instances, a response by participants fell into two categories. The application of descriptive analysis to these categories showed that the main categories of barriers towards using PwRC in the selected case projects were "Unsupportive regulations"

Participant	Client	Head-contractor	Designer	Supplier
Case study				
Case study 1 (Brickworks Shopping Centre)	C1P1 – 20 years' experience in construction project development	C1P2 – About six years' experience in the organisation	C1P3 – 11 years' experience in architectural management	C1P4 – seven years' experience in the organisation as the sale manager
Case study 2 (Mordialloc Freeway)	C_2P_1 – Senior project manager with extensive experience in project managing public infrastructure projects	C_2P_2 – 20 years' experience in the construction industry as a site engineer, project engineer and manager	C_2P_3 – 15 years' experience working as a design consultant	C_2P_4 – Highly experienced corporate communicator with a background in government, corporate, industry and community organisations, with a four-year employment history in the organisation
Case study 3 (Tonkin Gap Highway)	C_3P_1 – Experienced sustainability advisor responsible for overseeing projects and initiatives using or promoting the PwRC application	C_3P_2 – Four years' experience in the construction industry with a focus on major road infrastructure projects in the organisation	C_3P_3 – 18 years' experience in the organisation and was involved in the project as the technical director and oversaw the structural design of the work	C_3P_4 – Has worked in the organisation as the director since its establishment 10 years ago
Case study 4 (OneOneFive Hamilton Hill)	C_4P_1 – A senior development manager involved in the property industry for more than 30 years	C_4P_1 – A civil engineer and the director of the organisation with 20 years' working experience in the organisation	C_4P_3 – The director of a private company that specialises in landscape architects, urban design and sustainability consultancy	C_4P_4 – The director of the organisation with more than 27 years' experience in waste recovery in Western Australia

Source(s): Authors

Table 2. The summary of experience and expertise of the research participants in the case studies

(n = 13), "Inconsistency of PwRC quality, performance and warranty" (n = 9), "Limited availability of PwRC" (n = 9) and "Lack of expertise and understanding of PwRC utilisation" (n = 9) (Figure 2b).

The most referred to barrier category, "Unsupportive regulations", represents several issues within current state waste regulations. Primarily, it relates to the complex and hard-to-achieve requirements stipulated in PwRC specifications. According to the interviews, these requirements practically limit the application of these resources in the sector. For instance, C_2P_2 indicated that *"it is traditional specifications [that] don't allow it [using PwRC] . . . [if we consider] the pipe for instance. The specification said it had to be a concrete pipe. So, if I was just to follow the specifications then I can't do the recycled asphalt, well, there was no testing regime [so] there was no accepted product. So, the challenge is to get the specifications that invite innovation, you know, the specifications traditionally prevent innovation"*.

The other complexity of the current waste regulation system in Australia is the fact that the regulatory framework is established on a state basis. As a result, each state has its own regulations and guidelines (Shooshtarian *et al.*, 2020c, d), and a range of materials

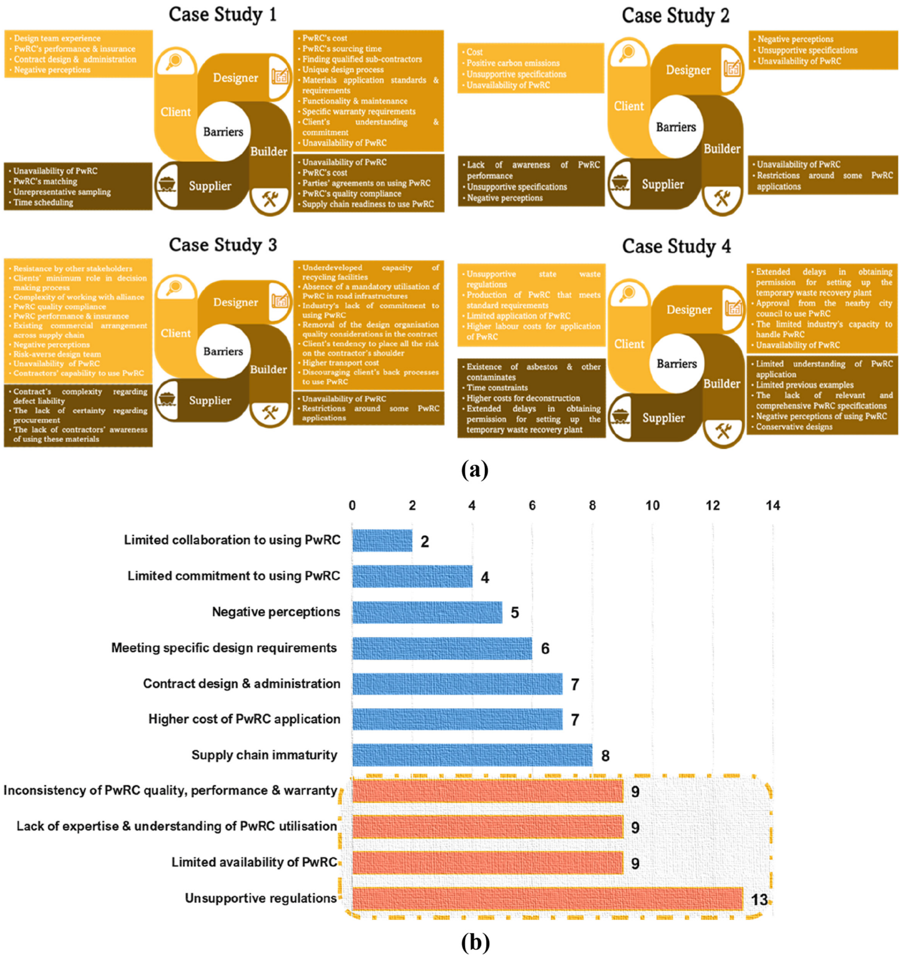


Figure 2.
(a) The barriers to using PwRC in the selected case studies (b) Frequency distribution of barrier categories

Source(s): Authors

specifications and standards are applied across Australian states and territories. Other barriers classified under this category were the frequency and routines of sampling of PwRC sourced from different construction and demolition sites (Case Study 1), lack of obligation to use PwRC in infrastructure projects (Case Study 3) and obtaining permission to set up the temporary waste recovery plant and approval from city councils to use PwRC (Case Study 4).

Despite the increased C&D waste recovery across Australia (Blue Environment, 2023), the issue of PwRC availability was frequently highlighted in the interviews. Indeed, the procurement of quality PwRC that can meet applicable materials specifications and demonstrate consistent quality persists as a major hurdle. This was a critical issue, particularly in large-scale projects such as Case Study 1 where certain undersupplied PwRC were specified to be reused in the project in large quantities. Furthermore, the supply of PwRC was found to be challenging at sites located far from the metropolitan areas. This issue was frequently noted by respondents from the builder category who were responsible for sourcing these materials for the study projects (Figure 2). C_3P_1 maintained that *"it's another commercial challenge, which is around getting enough product at the right time at the right cost. So, once you've proven that it's okay to be used, then it'll be can we get it when we need it and get it for a reasonable price and it's competitive"*.

Working with PwRC requires special expertise across the supply chain. Until this expertise and maturity become fully developed, the utilisation of PwRC is unlikely to become a business-as-usual practice in the sector. This barrier category represents issues such as the design team's poor experience and risk aversion, limited understanding of the process, lack of previous experience in applying these resources in construction and difficulty finding qualified contractors with the capability to use PwRC. C_1P_3 stated that *"I guess there's a process involved in finding the collaborators . . . it was something that took time and was part of the challenges"*.

The last important barrier according to the responses refers to the quality of PwRC and the warranty thereof. This barrier deals with a long-lasting issue in the sector that has been reported to significantly limit PwRC application and is linked with the risk of material failure, cost of the project, delays in project delivery and the unwillingness to use these materials in the case project. The PwRC quality issues emerge from various factors such as the inability to meet materials specifications requirements, carbon emission goals or expected performance, the existence of contaminants, limitations concerning sourcing materials with similar physical and visual quality, and requirements for special maintenance practices and warranties (Figure 2). This category was among the main concerns expressed by the client and supplier respondents. For instance, C_1P_1 explained that *"if you have got performance requirements for, something that's structural or load bearing, or needs to be able to be cleaned in a certain way, or slip resistance, or whatever it might be, often, the easiest way to achieve those is with brand new products that have been, you know, factory tested, whereas you can't always guarantee that we've recycled or salvaged materials in particular"*.

4.3 Motivations to using PwRC

In response to the question enquiring about the main motivations for using PwRC in the selected case studies, research participants referred to 64 factors (Figure 3a). Analysis of the responses suggested the four stakeholders provided a similar quantity of motivation factors during the interviews.

The motivational factors were categorised into 17 groups (Figure 2b). The descriptive analysis showed that "environmental benefits" ($n = 13$), "ensuring the competitive advantage and future-proofing" ($n = 9$), "strong support by major stakeholders" ($n = 5$), "social image and recognition for environmental sustainability" ($n = 5$) and "contractual obligation" ($n = 5$) were the top five categories of motivations for using PwRC in the four case studies.

The category of "environmental benefits", which represents about 17% of the total motivation factors, included reduced carbon emissions, less waste landfilling, project vision to be green, solving the issue of PwRC stockpiling and reducing virgin material extraction. Applying PwRC in the case studies resulted in the reduction of raw material extraction, waste disposal and some carbon savings. With respect to carbon emissions, however, as was reported by C_2P_1: *"Sometimes you get environmental benefits in one area, but you're harming the environment in another area. So, there were trade-offs that sometimes did not work in favour of recycled materials"*. The production and consumption of PwRC itself requires energy in transportation, processing and application. Hence, construction environmental assessments need to consider the implications of PwRC utilisation to ensure it will deliver the expected environmental benefits without unintended consequences.

The second most important motivation category refers to the concept of future-proofing. As it currently stands, the Australian construction industry is preparing to shift towards

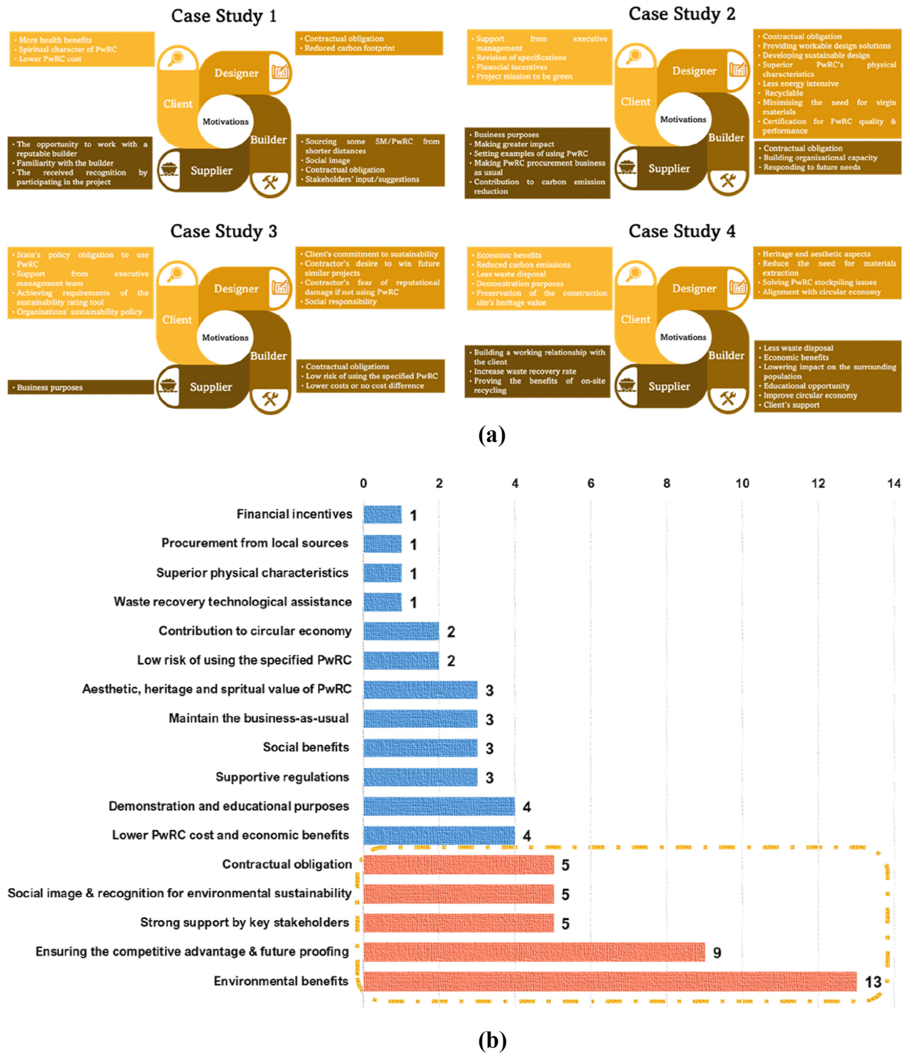


Figure 3.
(a) Motivations to use PwRC in the case study construction projects (b) The distribution frequency of the main motivations categories for using PwRC

Source(s): Authors

adopting sustainable and circular economy models. Soon, construction projects (including public infrastructure projects) will require contractors who can effectively handle PwRC. C_3P_3 indicated that "*. . . you also have to realise that when you win a contract as an alliance, a lot of the things that motivate the client to pick a certain team is based on their team, their people and their attitude towards things like sustainability*".

Variation in participant views regarding the cost of PwRC was an intriguing finding of this investigation. In seven instances, the relevant expenses for using PwRC were viewed as an impediment, but in four instances, the participants were more interested in the associated economic benefits. This observation emphasises the unpredictability and multiplicity of factors that affect the final cost of the PwRC application. These variables include the project type, distance, application areas and financial incentives eligible to project owners that utilise PwRC. Similar results were achieved in the case of the role of regulations, being both supportive (motive) and unsupportive (barrier).

4.4 Mitigation strategies to overcome barriers to PwRC application

In the interviews, 45 factors were identified as the main strategies to reduce the impact of challenges faced in the case study projects when using PwRC (Figure 4a). The participants from the four stakeholder groups almost equally contributed to the identification of strategies to enhance the use of PwRC in construction projects.

As illustrated in Figure 4b, these strategies were categorised into 13 groups, of which the top two categories are: ‘effective education, investigation, and demonstration activities” and ‘effective project management planning”.

Efforts aimed at educating stakeholders, together with encouragement and enforcement, are often referred to as the three pillars of sustainable C&D waste management (Wahi *et al.*,

Source(s): Authors

Figure 4. (a) The main strategies to address barriers regarding the use of PwRC in construction projects (b) The main strategies to reduce the impact of challenges reported in the interviews

2016) and are shown to motivate further uptake of PwRC (Shooshtarian *et al.*, 2020a). This category represents several strategies: developing demonstration projects, studying emerging PwRC and new applications for these resources, continual education of contractors such as preparing mandatory site visits for contractors, developing local knowledge, and education on specific PwRC design requirements and complexities.

The second broadly referenced category deals with project management planning strategies such as effective time planning, communications and reasonable budgeting. C_4P_3 indicated that it is *"... ultimately about good planning, understanding the timeline implications. Certainly, that means the timeframe challenge is you would hope that early engagement with regulators helps identify risk and ensuring that that all parties understand what the intention of the project is"*. This observation highlights the importance of the project management team to the successful completion of PwRC-using projects. Project managers are among the top four out of 20 stakeholders recognised as having an impact on the successful implementation of C&D waste management in Australia (Shooshtarian *et al.*, 2022e).

4.5 Comparative analysis by project and stakeholder group

Further analyses were conducted to compare the major categories created for reporting different determinants of PwRC application (i.e. motivation, barrier and mitigation strategies) across the case studies as well as by the study stakeholder groups. The analytical focus was placed on the categories with the largest frequency in each case study and stakeholder group. In some instances, stakeholders selected more than one category, hence expanding the number of categories compared.

As can be seen in Table 3, participants in each case study prioritised the defined categories differently. Such findings show that internal and external factors can impact construction projects to different degrees and/or in different directions. Hence, while the findings based on the aggregated data provide useful insights into PwRC application, precise planning for using these resources needs to be individual and subject to contextual variables, including evident and latent constraints and opportunities.

A similar trend is evident from the comparison of categories between the stakeholders (Table 3). The findings show that stakeholders did not have similar perceptions with respect to PwRC application. In terms of barriers, stakeholders only expressed two (i.e. inconsistency of PwRC quality, performance and warranty and unsupportive regulations) out of five categories as barrier. This ratio was one (i.e. environmental benefits) in five and one (i.e. education, investigation and demonstration activities) in six for motivations and strategies, respectively. For instance, "environmental benefits" was the most important factor only for the projects' clients and designers.

5. Discussion

5.1 Comparative analysis of the research findings

This section offers a comparative analysis between the findings of this study and previous research on barriers, motivations and strategies for optimal uptake of PwRC. A summary of this analysis is also presented in Table A2, where the key factors influencing their utilisation are tabulated.

5.1.1 Barriers. The study showed that unsupportive regulations, limited availability, lack of expertise and understanding of application and inconsistency of quality, performance and warranty issues are the major barriers to PwRC application (Figure 2). In China, Liu *et al.* (2020) reported that waste regulations are the most influential factor in the C&D waste recovery industry and have cascading effects such as limited uptake of PwRC. In Australia,

Case study	Barriers	Motivations	Strategies
1	Inconsistency of PwRC quality, performance and warranty	Ensuring a competitive advantage and future-proofing Social image and recognition for environmental sustainability Strong support by key stakeholders Supportive regulations	Setting clear expectations and understanding of the PwRC application
2	Unsupportive regulations	Ensuring a competitive advantage and future-proofing Environmental benefits	Strong support from key stakeholders
3	Contract design and administration	Ensuring a competitive advantage and future-proofing Social image and recognition for environmental sustainability Strong support by key stakeholders Supportive regulations	Effective project management planning Effective project contract development
4	Unsupportive regulations	Environmental benefits	Education, investigation and demonstration activities
Stakeholders			
Client	Inconsistency of PwRC quality, performance and warranty	Environmental benefits Supportive regulations	Education, investigation and demonstration activities
Builder	Limited availability of PwRC Unsupportive regulations	Contractual obligation	Education, investigation and demonstration activities
Designer	Unsupportive regulations	Ensuring a competitive advantage and future-proofing Environmental benefits	Early involvement of key stakeholders Education, investigation and demonstration activities Effective material audits and testing Effective project management planning Setting clear expectations and understanding of the PwRC application
Supplier	Contract design and administration Inconsistency of PwRC quality, performance and warranty Supply chain immaturity Unsupportive regulations	Ensuring a competitive advantage and future-proofing Maintain the business-as-usual	Education, investigation and demonstration activities

Source(s): Authors

Table 3. Summary of comparative analysis of the PwRC application determinant across the study projects and stakeholders

"overregulation, tough acceptance criteria, as specified in PwRC specifications, and increased testing" have been identified as the top barriers to effective C&D waste management (Shooshtarian *et al.*, 2022c, d). Similarly, Wijayasundara *et al.* (2022) and Ho *et al.* (2023) reported that a lack of industry standards and specifications guiding the use of PwRC in the Australian context is a primary barrier, particularly for infrastructure projects.

Among the various regulations being implemented, PwRC specifications play a pivotal role. Previous studies have also identified PwRC specifications as a major hurdle not only to their application (Park and Tucker, 2017; Knoeri *et al.*, 2011) but also to effective C&D waste management (Shooshtarian *et al.*, 2022c, d; Liu *et al.*, 2020), the creation and stimulation of markets for PwRC (Shooshtarian *et al.*, 2022a, b) and, more importantly, the implementation of circular economy principles (Shooshtarian *et al.*, 2023; Ho *et al.*, 2023).

The availability of PwRC can indeed pose a significant constraint on their application. However, only a limited number of studies have recognised this issue as a major barrier. This might be due to the fact the supply and demand for PwRC is traditionally skewed towards a lower demand (Wang *et al.*, 2014). A recent study by Tennakoon *et al.* (2023) suggested that the utilisation of reprocessed structural timber is constrained by its limited availability both in the quantity and quality required according to construction project requirements.

Lack of expertise and understanding of PwRC applications is also cited as a major barrier in several publications (Wijayasundara *et al.*, 2022; Jin *et al.*, 2017). For instance, Wijayasundara *et al.* (2022) suggested that if local authorities were to acquire knowledge about the possible uses of different PwRC, they would be more self-assured when including requests for these resources in their infrastructure project proposals. Similarly, Jin *et al.* (2017) indicated that gaining experience in the utilisation of PwRC would offer professionals a more positive perception of the quality of these products.

5.1.2 Motivations. Participants indicated that environmental benefits and the ability to improve their organisational competitive advantage and future-proofing are the two major motivations to use PwRC in their projects (Figure 3). This finding matches those in a study conducted in China (Jin *et al.*, 2017) where the researchers observed that environmental benefits (e.g. saving space from landfills, saving natural materials and reducing transportation) and increasing business opportunities for construction organisations are the major benefits of utilisation of PwRC.

Interestingly, the study findings regarding the financial incentive being a negligible motivation for PwRC utilisation contradict those of other studies (Ho *et al.*, 2023; Bolden *et al.*, 2013; Oyedele *et al.*, 2014). These studies found that financial benefits arising from the cost difference between PwRC and virgin resources are a major motivator in this space.

5.1.3 Strategies. As per Figure 4, the two top strategies for optimal uptake of PwRC included effective project management planning strategies and education, investigation and demonstration activities.

Effective project management planning is paramount to the smooth application of PwRC in construction projects. Planning is the stage at which the decisions for quality, budget, time scheduling and communication styles are made. All of these factors contribute to the successful application of these resources in construction projects.

Education, investigation and demonstration activities should support the growing appetite for using PwRC in building and construction projects. The importance of education has been particularly emphasised in previous studies (Ho *et al.*, 2023; Polonsky *et al.*, 2022; Oyedele *et al.*, 2014). In Australia, several educational opportunities target various stakeholders to improve their knowledge of C&D waste management including using PwRC in construction projects (Shooshtarian *et al.*, 2022c, d).

Demonstration projects can particularly drive the broad application of PwRC through attitudinal and behavioural changes among the major stakeholders (Yu *et al.*, 2021; Elena *et al.*, 2022). The potential impact of such initiatives is shown by Liu *et al.* (2013), who found that the creation of demonstration projects for renewable energy applications in China has activated the entire market, i.e. both demand and supply sides, and as a result, such applications have become more popular. This fact was clearly reflected by C_4P_1: *"the purpose of these projects for us is to be able to demonstrate to the industry. We want to be showing that we're pushing the boundaries and trying to, I suppose, provide demonstration projects that show what can be done and within a normal commercial environment"*. Knowing the importance of this strategy, the owners of all studied projects offered site visits to provide learning opportunities for individuals working in the relevant fields. Such efforts may provide a solution to an issue reported in Active Sustainability (2020) study in which two out of five respondents, residing in Western Australia, were not able to identify any projects where PwRC were used.

5.1.4 Disparity in stakeholders' perceptions of PwRC utilisation. The findings regarding diverse stakeholders' perceptions of using PwRC in construction projects align with prior research conducted in various regions, including China (Henry and Kato, 2012; Jin *et al.*, 2017), New Zealand (Balador, 2020) and Australia (Tennakoon *et al.*, 2023) itself.

Tennakoon *et al.* (2023) reported that while clients are primarily concerned about the cost, construction practitioners focus more on risks associated with the use of PwRC. These findings clearly illustrate the intricate decision-making landscape within the building and construction sector. They also underscore the necessity for a shared understanding of the benefits associated with the adoption of PwRC in construction projects. Furthermore, the research filled the gap that was previously identified by Udawatta *et al.* (2018) concerning the need to study the variations in waste management practices across different project types and among different stakeholder groups in Australia.

5.2 Implications for research, practice and society

This section helps identify how the findings contribute to advancing research knowledge, how practitioners can apply the findings in their work and the potential societal impacts of the study.

5.2.1 Implications in research. 'Unsupportive regulations' were identified as a top barrier to using PwRC. These regulations often refer to rigid material specifications (e.g. a pipe specification stipulates it must be made from concrete), restricting alternative material use and resource innovation. This finding prompts the question: What other specifications are hindering the widespread adoption of PwRC? Research in this area should be tailored to each Australian state, as each has its own regulations and guidelines. Further exploration on this matter is imperative to establish a baseline for potential substitutions by PwRC through either primary or secondary data. This will inform policies that enable the utilisation of PwRC and drive a circular economy in the building and construction sector.

Another challenge is the scarcity of PwRC. What steps must be taken to increase the availability of PwRC for construction projects? This is supported by previous research indicating that, in Australia, plastic preprocessors struggle to source enough material, often juggling between available materials and manufacturers' needs (Cáceres Ruiz and Zaman, 2022). Issues like plastic waste collection practices and efficiency, as well as the management of C&D waste, warrant investigation. Understanding the movement of plastics through various industry supply chains is key to identifying the best approach for their recovery at the end of life.

The quality of PwRC raises concerns: How can users be assured that it meets the necessary material technical and functional requirements? Considerations such as material maintenance and warranty also need to be addressed for a comprehensive understanding of its reliability. While there are national (e.g. AS 2070 Plastics materials for food contact use) and international (e.g. ISO 15270 Plastics – Guidelines for the recovery and recycling of plastics waste) guidelines that provide direction in the recovery process, specifications for construction use appear to be an area yet to be thoroughly explored (MRA, 2021).

5.2.2 Implications in practice. Practitioners in the construction industry (e.g. project managers and designers) face complex regulatory environments when using PwRC. Further research into specific regulatory challenges and opportunities in different Australian states can inform policymakers and regulatory bodies on potential improvements and guide project compliance.

The findings underscore the complexity and unpredictability of costs associated with PwRC use. To mitigate this uncertainty, construction practitioners could consider economic and regulatory factors on a case-by-case basis, understand the varied nature of costs considering project type, distances from suppliers or vendors and available financial incentives, and align economic incentives with their financial strategy when incorporating PwRC.

The results highlighted the need for a comprehensive approach to using PwRC in construction projects, including setting clear expectations, collaborating, engaging in educational initiatives and demonstration projects, and understanding PwRC application and effective management planning. The vital role of project managers is emphasised, given their crucial contribution to the success of PwRC implementation projects.

5.2.3 Implications in society. The emphasis on "environmental benefits" as a significant motivation for using PwRC indicates a societal concern for environmental sustainability within the construction industry. This commitment is manifested through efforts to reduce carbon emissions, waste landfilling and incorporate environmentally sound practices, highlighting a broader societal commitment to addressing climate change and minimising the construction industry's carbon footprint. Additionally, this research has implications for the growing sustainability awareness in the construction industry, which is driving the adoption of circular economy models, as seen in the 'future-proofing' category identified as the second most important motivation. Public infrastructure projects, in particular, are expected to prioritise contractors proficient in handling PwRC, reflecting a societal push towards circular practices in large-scale developments. Further studies on community perspectives could provide valuable insights into public perceptions of using PwRC in construction projects, offering information that would be useful for fostering public acceptance of PwRC in construction.

5.3 Required knowledge and changes in regulatory policies

To enhance the application of PwRC in the construction sector, a profound understanding of product specifications, quality control, supply chain management, environmental impact assessment and effective project management is essential. This involves acquiring knowledge on maintaining consistent quality of PwRC, developing expertise in sourcing and procurement, understanding the environmental trade-offs and fostering strategies for effective communication and risk assessment in project management. Additionally, ongoing education, training and the development of demonstration projects are crucial for raising awareness and showcasing the viability of PwRC in commercial environments.

Beneficial regulatory changes are also pivotal for overcoming barriers to PwRC utilisation. This includes revising traditional specifications to foster innovation, harmonising regulations across states and territories and implementing regulations that promote the use of PwRC in infrastructure projects. Offering financial incentives for projects utilising PwRC, providing permissions for waste recovery plants, and supporting educational initiatives and demonstration projects can further facilitate the adoption of PwRC.

Bridging these knowledge gaps and making strategic regulatory amendments are integral steps towards overcoming the challenges of PwRC application. These measures will not only foster sustainable practices in C&D waste management but also drive the industry towards adopting circular economy models, thereby contributing to environmental conservation and sustainable development.

6. Conclusions

Globally, the building and construction sector deeply lacks resource efficiency. It consumes a significant proportion of global raw materials and generates billions of tonnes of C&D waste each year. In Australia, although statistics indicate recent higher recovery rates, this has not significantly translated into increased adoption of PwRC, as reports have also demonstrated excessive stockpiling of these resources. Hence, this study was conducted to understand the factors influencing the use of these resources in the building and construction sector by applying a multiple-case study approach.

The findings demonstrated the main barriers, motivations and opportunities for increasing the utilisation of PwRC resources in four construction projects. The thematic and descriptive analyses revealed that the study factors might affect the utilisation of PwRC to different degrees and/or in different directions. Hence, while the aggregated data in this study provide useful insights into PwRC application, precise planning for using these resources is subject to a wide array of contextual variables, including evident and latent constraints and opportunities.

The study shows that the primary objective driving industry practices to divert waste from landfills and reduce the burden on virgin materials is increasing efficiency. The creation of C&D markets has the potential to extend the life of materials and reduce associated greenhouse gas emissions. The findings suggest that there is a significant opportunity for stakeholders to adopt more sustainable waste management practices, and the use of institutional drivers can help achieve this goal.

The study identified the top four barriers to using PwRC in construction projects as "unsupportive regulations", "limited availability of PwRC", "lack of expertise and understanding of PwRC utilisation" and "inconsistency of PwRC quality and performance and issues around the warranty". The research findings will have policy implications as "unsupportive regulations" were recognised as the top barrier. The current climate of opinion around the waste recovery system in Australia urges governments to devise policies that facilitate the utilisation of PwRC and drive a circular economy in the building and construction sector. As such, policymakers can use the information provided in this study to develop supportive policies that create a level playing field for all parties operating in PwRC supply chains. For instance, informed policies can incentivise the production and purchasing of PwRC in the sector. Addressing these challenges presents an opportunity for increased sustainability and the advancement of a circular economy within the building and construction sector.

The study's main theoretical contribution is the delineation of three distinct research directions, as detailed in Section 4.2.1, encompassing the examination of regulatory constraints affecting PwRC usage, the exploration of their supply chain challenges quality assurance in this context.

According to the responses from the research participants, the barriers identified in this study should primarily be addressed through "education, investigation, and demonstration activities" and "effective project management planning". Further research should investigate how the outlined strategies may change stakeholders' attitudes and result in the optimised use of PwRC in construction. In addition, policy reform initiatives must pay particular attention to these measures as a part of a road map leading to the optimised use of PwRC.

This study also identified the two major motivations for using PwRC resources to be "environmental benefits" and "ensuring competitive advantage and future-proofing". New policies can foster greater utilisation of PwRC in the building and construction sector by enabling motivations for product uptake.

A comparative analysis of the findings demonstrated the disparity in stakeholders' perceptions of PwRC utilisation. The comparative analysis carried out on this study also allowed it to bridge the research gap previously identified about the need to study variations of waste management practices by various projects and stakeholders. The research also makes a practical contribution to the industry through a suite of actionable strategies to increase the uptake of PwRC. The strategies are mostly focussed on stakeholder education, the regulation that supports PwRC and project management planning. The two major motivations – referring to two of the three pillars of sustainability (economy and environment) – provide a basis for organisational changes to ensure achieving sustainability in construction activities.

A significant limitation of the study is the challenge of generalising the findings from case studies. Generalisability is a common concern in qualitative research, and addressing this issue requires careful consideration of leveraging specific strategies. This study employed several strategies to address this issue. Firstly, the study clearly communicated the research methods, data collection procedures and analytical techniques, allowing readers to understand and assess the study's quality and relevance. Secondly, the research team conducted pilot interviews with waste professionals to refine the interview questions, enhancing the study's internal reliability. Thirdly, the study conducted a comparative analysis between the stakeholders and case projects to identify generalisable themes and factors. Lastly, the study adopted purposive sampling to ensure that case studies are relevant and informative for the broader context.

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Further reading

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Appendix

Project features	Case study 1	Case study 2	Case study 3	Case study 4
Name of project	Burwood Brickworks Shopping Centre	Mordialloc Freeway	Tonkin Gap Highway	OneOneFive Hamilton Hill
Construction type	Commercial	Infrastructure	Infrastructure	Residential
Client	Frasers Property Group	Major Road Projects Victoria	Main Roads Western Australia	WA Development
Budget (AUD m)	\$120 m (AUD)	\$375 m (AUD)	\$400 m (AUD)	\$2.7 m (AUD)
Demonstration of environmental sustainability	• Living Building Challenge® • GBCA	• ISC	• ISC	• UDIA
Project duration	2018–2019	2019–2021	2021–2023	2018–2019
Recycled products used (quantity/tonnes where provided)	• The use of crushed concrete in the sub-base of bitumen • The use of materials from slab form working as hanging timber and timber cladding in the ceiling • The use of second-hand brick purposed into tiles and concrete in floors • The use of crushed brick leftover as a finish on facades	• The use of 600 t of plastic waste in noise walls • The use of 270 kt of pavement material incorporating the maximum allowable recycled content • The use of 30 t of plastic waste in 100% recycled polypropylene plastic (PP) concrete reinforcing mesh • The use of 75 t of plastic waste in 100% recycled high-density polyethene (HDPE) stormwater drainage pipe	• The reuse of 296 kt of sand • The reuse of 105 kt of spoil (treated ASS) • The use of 27 kt of crushed recycled concrete • The use of 1.2 kt of reclaimed asphalt pavement	• The use of salvaged timber in landscaping features, e.g. shade structures and seating • The reuse of 40,000 clay bricks and roof tiles as aggregates underneath the drainage infrastructure • The reuse of old bricks to create brick walls and a brick toilet block • The reuse of crushed brick, tiles, concrete, etc., into the road sub-base replacing the need for newly mined materials like crushed limestone • The use of 2,425 m^3 of recycled concrete in retaining walls replaces the need for newly mined limestone • The use of 400 t of PwRC in different applications including constructing temporary truck access roads

Source(s): Authors

Table A1. Summary of the characteristics of the selected case studies

Research	Motivations	Barriers	Strategies	Data source
This research	• Environmental benefits • Enhancement of competitive advantage and future-proofing • Strong support by key stakeholders • Social image and recognition for environmental sustainability • Contractual obligations	• Unsupportive regulations • Limited availability • Lack of expertise and understanding of their usage • Inconsistency in their quality, performance and warranty issues	• Education, investigation and demonstration activities • Effective project management planning • Effective project contract development • Revise regulations in favour of PwRC utilisation	Interview/ case study
Ding *et al.* (2023)	n/a	n/a	• Standardisation for PwRC raw materials • Detail recycled product information • Recycled product performance testing and brand certification • Their promotion through media publicity	Survey
Ho *et al.* (2023)	n/a	• Lack of specific PwRC guidelines/ standards • Lack of understanding • Financial challenges	• Regulatory environment • Collaboration • Education	Interview
Wijayasundara *et al.* (2022)	n/a	• Availability of policy to facilitate green procurement • Availability of industry standards/ guidelines • Organisational/ individual perception of PwRC	• Strategic approach towards sustainable procurement • Organisational prioritisation of sustainable procurement • Organisational ownership to drive sustainable procurement and coordinate across departments	Interview

(*continued*)

Table A2.
Summary of major (top three, where possible) barrier, strategy and motivation categories for using PwRC in construction projects identified in prior research

Research	Motivations	Barriers	Strategies	Data source
Polonsky *et al.* (2022)	n/a	• Federal government regulations • Lack of support from senior management • Lack of knowledge of PwRC • Lack of knowledge of sustainable procurement	• Organisational long-term goals • Senior management support • Awareness of sustainable procurement of PwRC	Literature review
Jin *et al.* (2017)	• Complying with relevant governmental policies • Saving space from landfills, reducing the demand for new waste landfills • Saving natural materials	• Lack of demand from the client • Lack of supervision and regulations • Lack of industry standards • Lack of industrial awareness and support for PwRC	• Mandatory requirements or financial incentives from governmental authorities • Categorising recyclable wastes according to the application of PwRC • Including PwRC in the early project stages	Survey
Oyedele *et al.* (2014)	n/a	• Architects and design engineers do not consider PwRC during project design and specification • Lack of positive perception from clients who drive the project process • Uncertainty on PwRC quality	• Allocation of more points to the use of recycled materials in sustainable design appraisal tools • Government legislation that would set a target for the usage of recycled materials and products • Improved architects and contractors' supply chain alliances with suppliers/recycling companies	Survey
Bolden *et al.* (2013)	n/a	• Cost of PwRC • Lack of education regarding certain PwRC • Limited PwRC applications • Environmental benefits • Quality of PwRC	n/a	Survey

Source(s): Authors

Table A2.