Enhancing the Use of Products with Recycled Contents in the Australian Construction Industry

Final Industry Report
Project 1.85

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Preface

The Sustainable Built Environment National Research Centre, Australia, the successor to the Cooperative Research Centre for Construction Innovation, remains committed to making a leading contribution to innovation across the Australian built environment industry after more than two decades of operation. We are dedicated to working collaboratively with industry and government to develop and apply practical research outcomes that improve industry practice and enhance our nation's competitiveness.

We encourage you to continue to draw on the results of our Centre's applied research to deliver tangible outcomes for your operations. By working together, we can transform our industry and communities through enhanced and sustainable business processes, environmental performance and productivity.

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Executive Summary

In Australia, construction and demolition (C&D) activities have substantially grown over recent decades, leading to the generation of a large amount of waste. The C&D waste stream therefore accounts for 38 per cent of the total waste generated, reaching 29 megatonnes (Mt) annually.[1] The average annual growth of C&D waste generation is currently at 2.4 per cent, and about 6.4 Mt of this waste stream is landfilled.

As of 2021, the C&D waste recovery rate reached 78 per cent, meaning that a large quantity of products with recycled content (PwRC) is being produced annually. However, the latest reports from private and public sectors highlight the inadequate uptake of these valuable resources. Consequently, it is essential to comprehend how the utilisation of these materials is perceived by Australian industry stakeholders.

Therefore, this research aimed to contribute to the increased use of PwRC in the Australian construction industry. To achieve this aim, four objectives were set out to map a plan for optimised utilisation of PwRC in construction.

First, the perceptions of four key stakeholder groups (that is, client, builder, designer and supplier) regarding the application of PwRC in four construction projects (one commercial, two transport infrastructure and one residential) that were recently completed in Australia were analysed. The case study analyses revealed the major barriers, motivations and strategies towards the optimised use of PwRC in typical construction projects in Australia (Objective 1).

Furthermore, interviews with the 16 individuals from Australian stakeholder groups showed their opinions about the application of recycled product certifications (RPC). The interviews were completed by a separate case study of an existing organisation that issues RPC to better understand their operations and working mechanisms (Objective 2).

Through circular economy (CE) practices embedded with 'design for zero waste' and 'design for reuse/recycling' principles, much of the C&D waste generation could have been avoided or at least recirculated within the construction sector supply chain. Therefore, a comprehensive review of the existing published works was conducted to develop guidelines for implementing CE practices in the construction and infrastructure industry (Objective 3).

To ensure increased uptake, behavioural and attitudinal changes are important for the acceptance of PwRC, so this study focused on developing two training packages for Main Roads Western Australia (WA) and the WA Department of Communities (Objective 4). The content of the training packages was informed by previous and current SBEnrc C&D waste projects (P1.65, P1.75, P1.85). These packages were co-developed with core industry partners and provided the knowledge required to manage C&D waste operations and activities.

[1] Department of Climate Change, Energy, the Environment and Water (2022) National Waste Report. Canberra, Australia. Retrieved from https://bit.ly/3JOcx77.

1.0 Introduction

In Australia, construction and demolition (C&D) activities have substantially grown over recent decades, leading to the generation of a large amount of waste. The C&D waste stream therefore accounts for 38 per cent of the total waste generated, reaching 29 megatonnes (Mt) annually. The average annual growth of C&D waste generation is currently at 2.4 per cent, and about 6.4 Mt of this waste stream is landfilled. As of 2021, the C&D waste recovery rate reached 78 per cent, meaning that a large quantity of products with recycled content (PwRC) is being produced annually. However, the latest reports from private and public sectors highlight the inadequate uptake of these valuable resources. The increasing concerns in the construction industry about the quality, performance and durability of PwRC are hindering the widespread adoption of such products.[2]

Aim

The purpose of this project is to contribute to facilitating the use of PwRC in the Australian construction industry to make their application more mainstream in construction projects.

Industry Motivation

The inherent concerns of the industry in using PwRC are hindering the use of these products. This needs to be dealt with by developing an independent certification system, developing specific design guidelines and adopting education-related strategies to change behaviour and attitude for the better. Both the infrastructure and building sectors will benefit from the project outcomes.

Objectives

1. Identify factors influencing the use of products with recycled content in the construction industry in Australia and understand end-users' perceptions about the application of these products.
2. Explore the role of recycled product certification (RPC) programs in producing quality products with recycled content.
3. Create the circular design guidelines following the DfZw and DfR principles.
4. Develop stakeholder-guided behaviour change strategies through a co-design/co-created educational program for the construction industry.

Consequently, it is essential to comprehend how the utilisation of these materials is perceived by key Australian industry stakeholders. Particularly, reassuring them of the PwRC's quality and performance through appropriate schemes that certify these products may drive their usage in the construction industry. Similarly, informing the architecture and design community through circular design guidelines that follow 'design for zero waste' (DfZw) and 'design for reuse/recycling' (DfR) principles, together with developing training opportunities for other stakeholders in the industry, could offer sustainable solutions to achieve this goal.

[2] Active Sustainability (2020) *Expanding Reuse Opportunities for Recycled Construction Materials – Survey Findings*. Perth, Australia. https://bit.ly/3ZMao0l

2.0 Research Approach

The project's research approach consisted of a range of data collection methods that were employed for the four research objectives (Figure 1). To achieve the first two objectives, a review of current (published) literature was conducted to understand the main barriers and enablers of using PwRC (Objective 1) in the construction study followed by the assessment of the role of the RPC program in enhancing PwRC uptake (Objective 2). The review of the literature was complemented with the analysis of four (construction project) case studies in which PwRC were used.

The case study analyses targeted four stakeholder groups (client, builder, designer and supplier) who were found to have a key role in using PwRC in construction projects. These stakeholders were selected based on (1) the review of relevant literature,[3] (2) consultation with the project industry and government partners and (3) the fact that they cover a major section of the PwRC supply chain.

Objective 3 of the research was achieved through the application of structured qualitative content analysis to understand the issues related to DfZw and DfR in the construction industry. Grey literature was also included in the research, to ensure no relevant data from government and industry reports were overlooked. For Objective 4, two training packages were developed for the Department of Transport, Main Roads Western Australia (Main Roads WA) and the Department of Communities, all based in WA. The content of the training packages was informed by the previous and current SBEnrc C&D waste projects (P1.65, P1.75, P1.85). These packages provide the knowledge required to manage C&D waste operations and develop an environmentally and economically sound design for reuse/recycling and disposal operations for C&D waste material management.

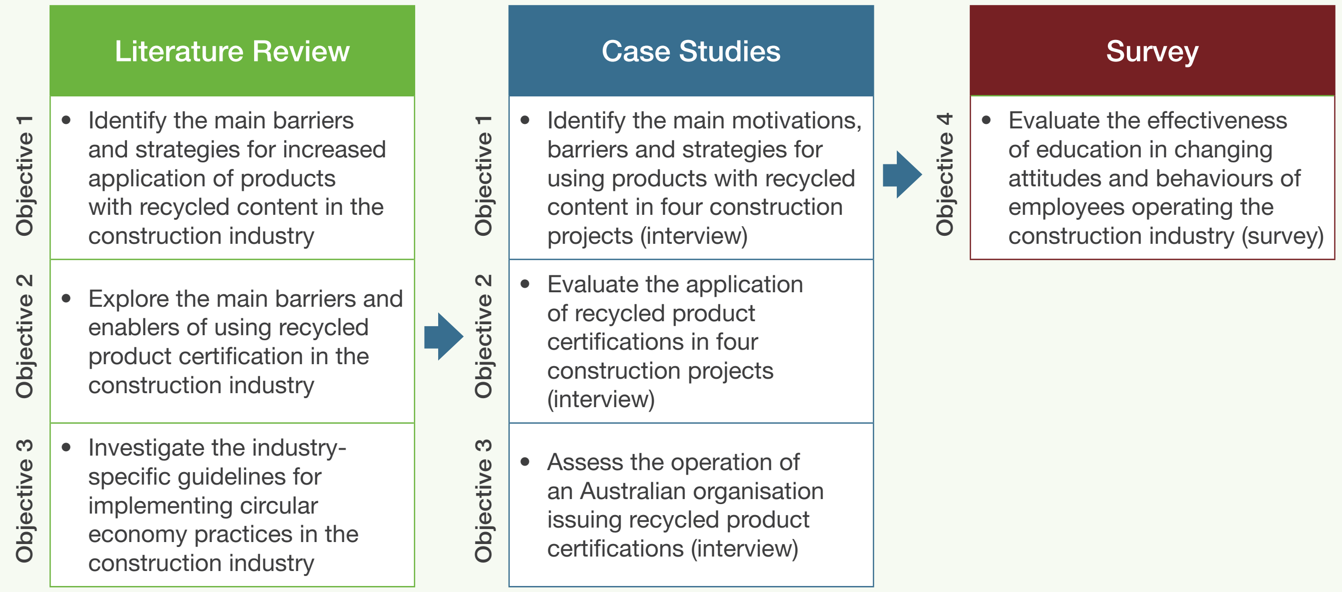

Figure 1. Visual Summary of Research Process in this Project

[3] Shooshtarian S, Caldera S, Maqsood T and Ryley T (2020) 'Using recycled construction and demolition waste products: A review of stakeholders' perceptions, decisions, and motivations', *Recycling*. 5(4): 31.

Review of Published Literature

The uptake of PwRC is still limited by various barriers that have been identified in previous studies. The results of the literature review showed that these barriers can be categorised under seven groups. Figure 2 briefly describes how these groups have hindered the application of PwRC in construction projects.

The literature in the field of C&D waste management offers solutions to mitigate the negative impacts of barriers identified above. The findings from the literature review suggest that the major strategies can be categorised into five groups. As depicted in Figure 3, the groups of strategies can assist the key industry stakeholders in advocating the use of PwRC in the construction industry.

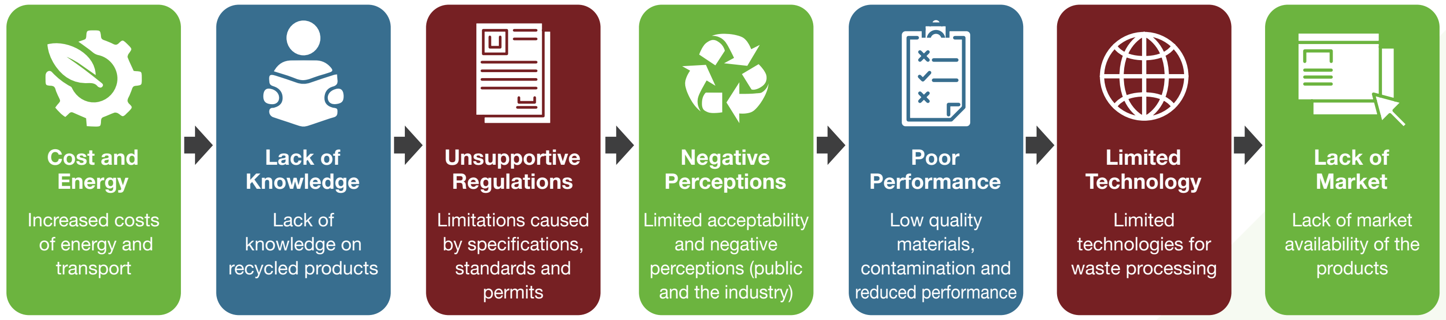

Figure 2. Primary Barriers to Using PwRC in Construction Projects

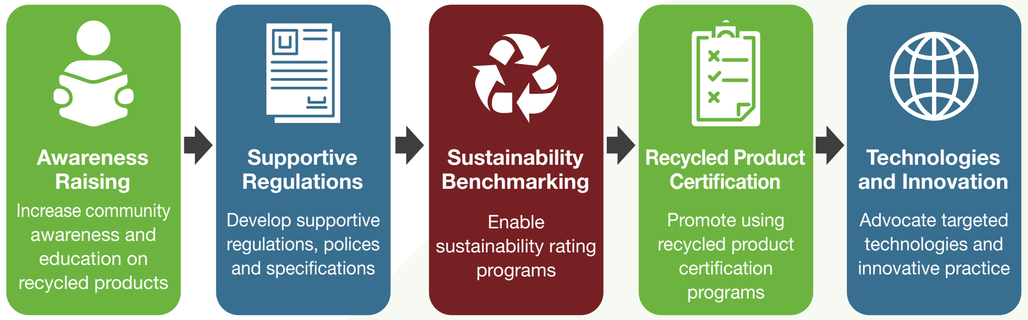

Figure 3. Primary Strategies for Using PwRC in Construction Projects

Case Study Analysis

In addition to a review of the literature, the project sought to understand the Australian context-specific conditions of using PwRC in construction projects. Hence, four construction projects, different in nature (that is, road infrastructure, commercial and residential) were selected for case study analysis. The main features of these projects are provided in Table 1.

The case study analyses focused on identifying the main motivations, barriers and strategies for making the use of PwRC business-as-usual. In each case study recently completed, four key stakeholders (client, builder, designer and PwRC supplier) were interviewed between May 2022 and January 2023. These projects used various tools and certifications to demonstrate achieving sustainable outcomes such as using PwRC.

Table 1: Summary of Characteristics of the Selected Case Studies

Project Features	Case Study 1	Case Study 2	Case Study 3	Case Study 4
Name of Project	Burwood Brickworks Shopping Centre (Melb, Vic)	Mordialloc Freeway (Melb, Vic)	Tonkin (Highway) Gap Project (Perth, WA)	OneOneFive Hamilton Hill (Perth, WA)
Construction Type	Commercial	Infrastructure	Infrastructure	Residential
Client	Frasers Property Australia	Major Road Projects Victoria	Main Roads WA	DevelopmentWA
Budget ($A)	$120 million	$375 million	$400 million	$2.7 million
Demonstration of Sustainability	• Living Building Challenge® • Green Building Council of Australia	• Infrastructure Sustainability Council of Australia (ISC)	• ISC	• Urban Development Institute of Australia
Project Duration	2018–19	2019–21	2021–23	2018–19
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 tonnes (t) of plastic waste in noise walls • The use of 270 kilotons (kt) of pavement material incorporating the maximum allowable recycled content • The use of 30t of plastic waste in 100% recycled polypropylene plastic concrete reinforcing mesh • The use of 75t of plastic waste in 100% recycled high-density polyethene stormwater drainage pipe	• The reuse of 296kt of sand • The reuse of 105kt of spoil (treated ASS) • The use of 27kt of crushed recycled concrete • The use of 1.2kt of reclaimed asphalt pavement	• The use of salvaged timber in landscaping features • The reuse of 40,000 clay bricks and roof tiles as aggregates beneath the drainage infrastructure • The reuse of old bricks to create walls and a toilet block • The reuse of crushed brick, tiles, concrete, etc. into the road sub-base • The use of 2,425 m3 of recycled concrete in retaining walls • The use of 400t of PwRC in different applications including constructing temporary truck access roads

Motivations for Using PwRC

The participants in the case studies were first asked about their main motivations for using PwRC in the construction projects. As illustrated in Figure 4, in response to the question research participants referred to 64 factors. The analysis of responses suggested the four stakeholders provided a fairly similar quantity of motivation factors during the interviews.

The motivational factors were categorised into 17 groups (Figure 5) to obtain definite groups of motivations. The descriptive analysis showed that 'environmental benefits' (n=13), 'ensuring the competitive advantage and future-proofing' (n=9), 'contractual obligations' (n=5), 'social image and recognition for environmental sustainability' (n=5) and 'strong support from the key stakeholders' (n=5) were the top five categories of motivations for using PwRC in the four case studies.

Case Study 1			
Client	**Designer**	**Builder**	**Supplier**
• More health benefits • Spiritual character or PwRC • Lower PwRC cost	• Contractual obligation • Reduced carbon footprint	• Sourcing some salvaged materials (SM)/PwRC from shorter distances • Social image • Contractual obligation • Stakeholder's input/ suggestions	• The opportunity to work with a reputable builder • Familiarity with the builder • The recived recognition by participating in the project

Case Study 2			
Client	**Designer**	**Builder**	**Supplier**
• Support from executive management • Revise specifications • Financial incentives • Project mission to be green	• Contractual obligation • Provide workable design solutions • Develop sustainable design • Superior PwRC's physical characteristics • Less energy intensive • Recyclable • Minimise the need for virgin materials • Certification for PwRC quality and performance	• Contractual obligation • Build organisational capacity • Respond to future needs	• Business purposes • Make greater impact • Set examples of using PwRC • Make PwRC procurement business as usual • Contribute to carbon emission reduction

Case Study 3			
Client	**Designer**	**Builder**	**Supplier**
• State's policy obligation to use PwRC • Support from executive management team • Achieve requirements of the sustainability rating tool • Organisation's sustainability policy	• Client's commitment to sustainability • Contractor's desire to win future similar projects • Contractor's fear of reputational damage if not using PwRC • Social responsibility	• Contractual obligation • Low risk of using the specifid PwRC • Lower costs or no cost difference	• Business purposes

Case Study 4			
Client	**Designer**	**Builder**	**Supplier**
• Economic benefits • Reduced carbon emissions • Less waste disposal • Demonstration purposes • Preservation of the construction site's heritage value	• Heritage and aesthetic aspects • Reduce the need for materials extraction • Solve PwRC stockpiling issues • Alignment with circular economy	• Less waste disposal • Economic benefits • Lower impact on the surrounding population • Educational opportunity • Improve circular economy • Client support	• Build a working relationship with the client • Increase waste recovery rate • Prove the benefits of onsite recycling

Figure 4. Motivations for Using PwRC in the Study Construction Projects

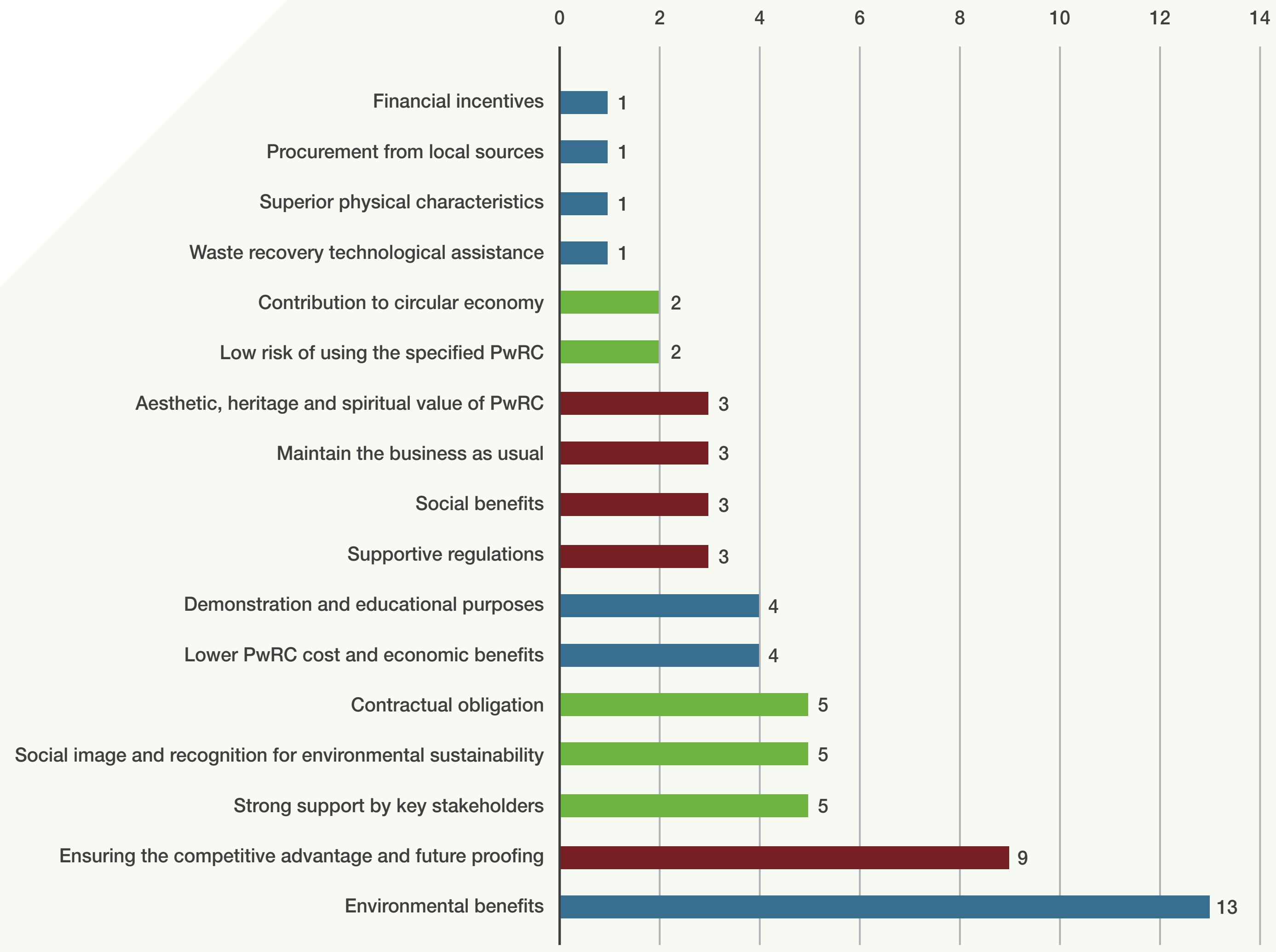

Figure 5. Distribution Frequency of the Main Motivation Categories for Using PwRC

Barriers to Using PwRC

The research participants reported 69 factors that were deemed to act as a hindrance towards the broad application of PwRC in the selected case studies (Figure 6). The two stakeholder groups (i.e., designers and builders) provided the greatest number of barrier factors in their responses to this question.

To better analyse these factors, they were organised into 11 categories. In three instances, one response by participants fell into two categories.

The application of descriptive analysis to these categories showed that 'unsupportive regulations' (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) were the main categories of barriers towards using PwRC in the selected case projects (Figure 7).

Case Study 1			
Client	Designer	Builder	Supplier
• Design team experience • PwRC's performance and insurance • Contract design & administration • Negative perceptions	• PwRC's cost • PwRC's sourcing time • Finding qualified sub-contractors • Unique design process • Materials application standards & requirements • Functionality & maintenance • Specific warranty requirements • Client's understanding & commitment • Unavailability of PwRC	• Unavailability of PwRC • PwRC's cost • Parties' agreement on using PwRC • PwRC's quality compliance • Supply chain readiness to use PwRC	• The opportunity to work with a reputable builder • Familiarity with the builder • The recived recognition by participating in the project

Case Study 2			
Client	Designer	Builder	Supplier
• Cost • Positive carbon emissions • Unsupportive specifications • Unavailability of PwRC	• Negative perceptions • Unsupportive specifications • Unavailability of PwRC	• Unavailability of PwRC • Restrictions around some PwRC applications	• Lack of awareness of PwRC performance • Unsupportive specifications • Negative perceptions

Case Study 3			
Client	Designer	Builder	Supplier
• Resistance by other stakeholders • Client's minimum role in decision making process • Complexity of working with alliance • PwRC quality compliance • PwRC performance & insurance • Existing commercial arrangement across supply chain • Negative perceptions • Risk-averse design team • Unavailability of PwRC • Contractor's capability to use PwRC	• Under-developed capacity of recycling facilities • Absence of a mandatory utilisation of PwRC in road infrastructure • Industry's lack of commitment to using PwRC • Removal of the design organisation's quality considerations in the contract • Client's tendency to place all the risk on the contractor's shoulder • Higher transport cost • Discouraging client's back processes to use PwRC	• Unavailability of PwRC • Restrictions around some PwRC applications	• Contract's complexity regarding defect liability • The lack of certainty regarding procurement • The lack of contractor's awareness of using these materials

Case Study 4			
Client	Designer	Builder	Supplier
• Unsupportive state waste regulations • Production of PwRC that meets standard requirements • Limited application of PwRC • Higher labour costs for application of PwRC	• Extended delays in obtaining permission for setting up the temporary waste recovery plant • Approval from the nearby city council to use PwRC • The limited industry capacity to handle PwRC • Unavailability of PwRC	• Limited understanding of the PwRC application • Limited previous examples • The lack of relevant & comprehensive PwRC specifications • Negative perceptions of using PwRC • Conservative designs	• Existence of asbestos & other contaminants • Time constraints • Higher costs for deconstruction • Extended delays in obtaining permission for setting up the temporary waste recovery plant

Figure 6. Barriers to Using PwRC in the Selected Case Studies

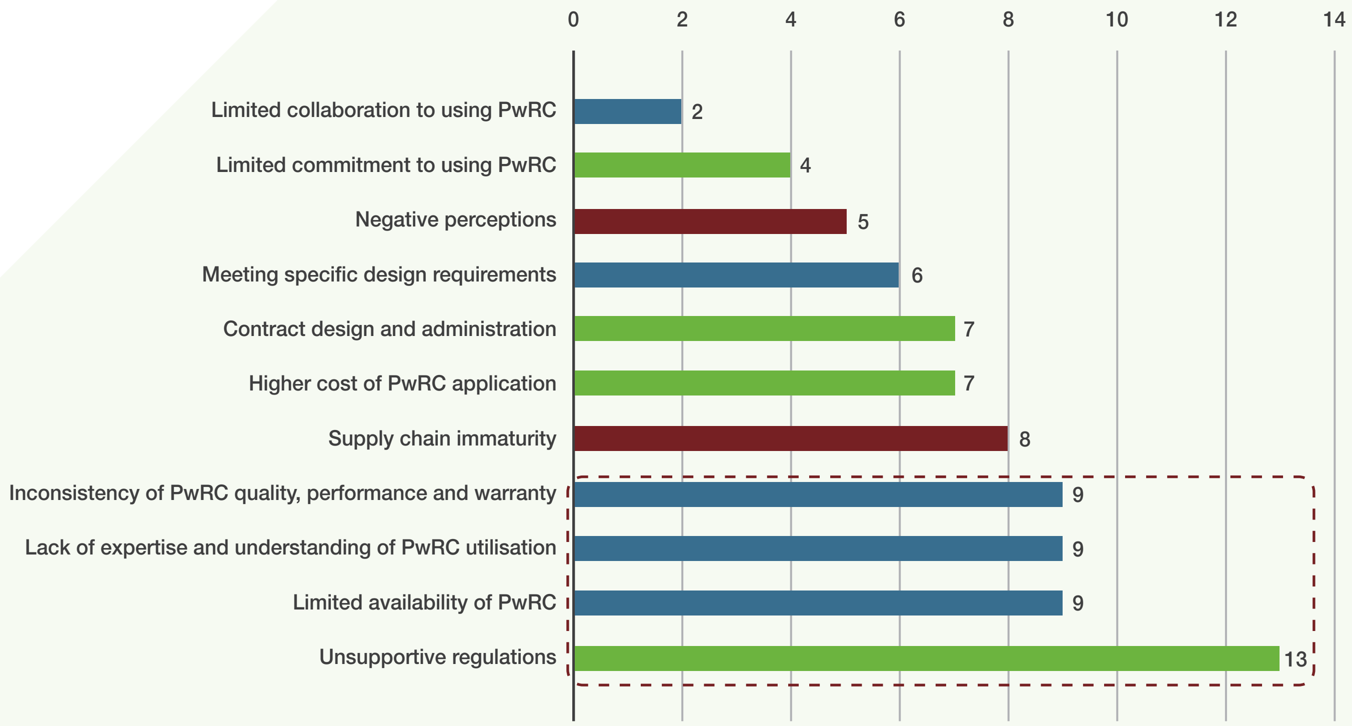

Figure 7. Frequency Distribution of Barrier Categories

Strategies for Increased Uptake of PwRC

During these interviews, 45 factors were identified as the main strategies to reduce the impact of challenges faced in these projects when using PwRC (Figure 8). The participants from the four stakeholder groups almost equally contributed to the identification of strategies to enhance using PwRC in construction projects.

As illustrated in Figure 9, these strategies were categorised into 13 groups, of which the top four categories were: 'effective education, investigation and demonstration activities' (n=11), 'effective project management planning' (n=6), 'effective project contract development' (n=5) and 'revising regulations in favour of utilisation of PwRC' (n=5). Efforts aiming to educate stakeholders together with encouragement and enforcement are among the three main approaches for sustainable C&D waste management.

Case Study 1

Client	Designer	Builder	Supplier
• Clear requirements of using SM/ PwRC in contracts • Normalise PwRC application across the supply chain • Legislate PwRC usage • Impose high landfill taxes on waste resources	• Early engagement of stakeholders • Develop understanding of budget requirements • Develop understanding of PwRC's cost performance • PwRC's post-occupancy	• Early involvment of key stakeholders • Set clear expectations of warranty conditions	• Broader sampling • Appropriate time scheduling

Case Study 2

Client	Designer	Builder	Supplier
• Financial incentives • Support from the client's project management team	• Develop demonstration projects • Test materials before applying them	• Share risk with the client • Allow more time to complete the project • Client's willingness to revise specifications • Allocate reasonable budget	• Support from authorities • Revise specifications • Have supportive individuals on project team • Study emerging PwRC

Case Study 3

Client	Designer	Builder	Supplier
• Establish auditing system • Mandate the use of PwRC in contracts • Financial incentive • Overhaul the existing long-term agreements • Positive experience using PwRC • Training, education & awareness-raising	• Promote the economy of scale • Allow reasonable lead time to recyclers to produce the required PwRC • Develop the right contractual mechanisms	• Sustainable supply of PwRC	• Effective project contract development • Government mandating of using PwRC • Improve communication and planning regarding PwRC procurement • Continual education of contractors

Case Study 4

Client	Designer	Builder	Supplier
• Early engagement of local council • Revise waste regulations • Study various PwRC applications • Demonstration case projects	• Effective time management planning • Early engagement of stakeholders • Mandate site visits for contractors	• Demonstration case projects • Education on design considerations • Develop local knowledge	• Effective project contract development • Demonstration case projects

Figure 8. Main Strategies to Address Barriers Regarding the Use of PwRC in Construction Projects

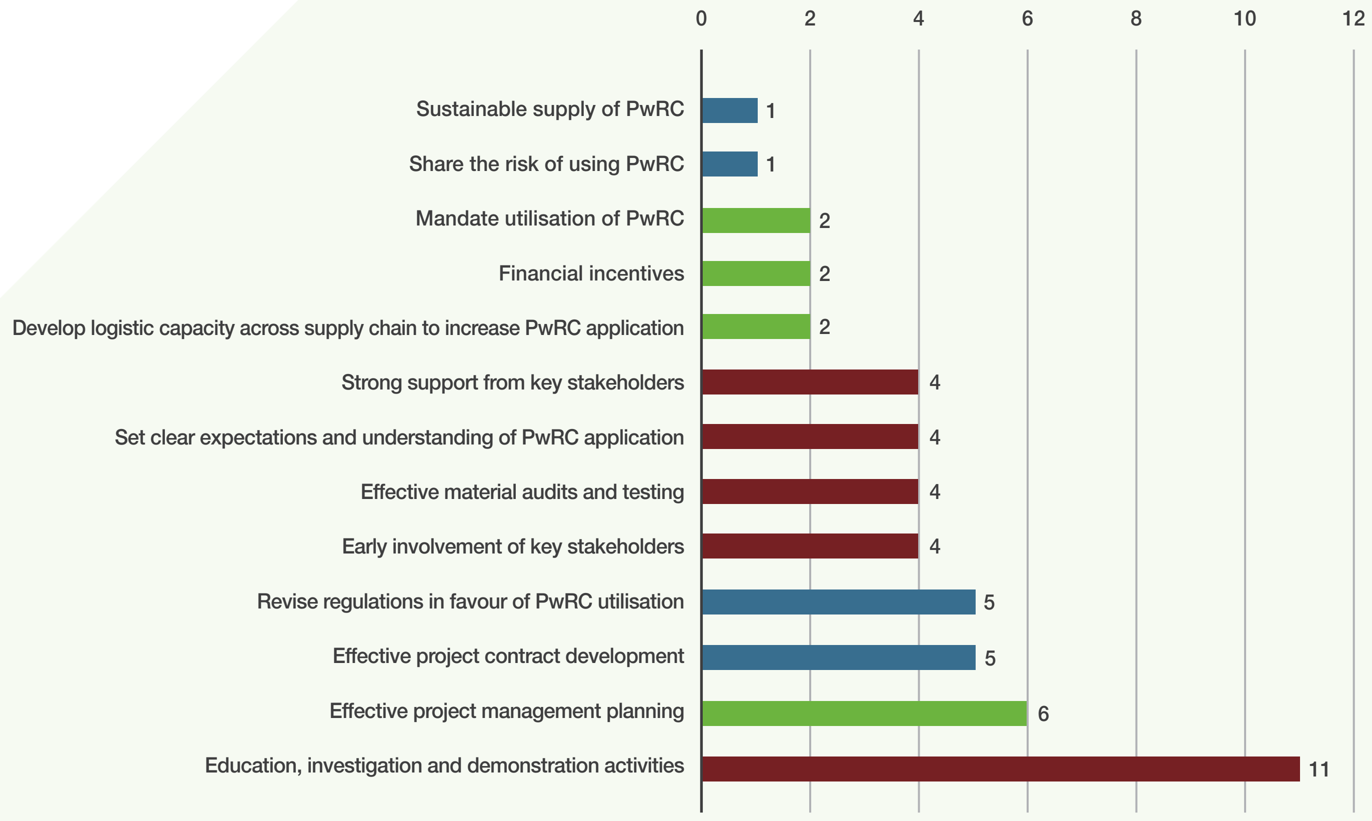

Figure 9. Main Strategies to Reduce the Impact of Challenges Reported in the Interviews

Although it has been suggested that the utilisation of PwRC is a sustainable solution for the management of C&D waste, there are still issues regarding the quality and performance of these products. Among the many strategies that have been proposed to address these concerns[4] (as shown in Figure 3), implementing RPC seems to offer a promising solution. RPC is a circular economy (CE)-based strategy that is designed to assure PwRC quality, performance, environmental friendliness and safety. These certification schemes reassure end-users of the satisfactory application of PwRC and may also include parameters such as energy use, air and water, emissions emerging from manufacturing, disposal and use of PwRC. When certification is awarded following technical material testing and quality control, it may optimise the adoption of PwRC, promote the sale of renewable products and ensure the smooth operation of the waste recovery industry. This initiative has been implemented worldwide, in Europe, the UK, the US and South Korea. The initiative has also been recently introduced to Australia, but current programs are still at the early stage of development and adoption. Hence, this project attempted to understand the role of RPC in accelerating the use of PwRC in the Australian construction industry. This attempt consists of three steps: (1) reviewing global and Australian literature on the main barriers and enablers of application RPC; (2) analysis of key stakeholders influencing the use of PwRC in four construction projects; and (3) analysis of operation of one Australian organisation issuing RPC for C&D waste-derived products.

Key Barriers to the Application of RPC: Literature Review

Despite the long history of the introduction of RPC to various industries,[5] their full implementation in the construction industry is rather recent. It is important to note that the number of publications detailing the problems associated with their actual use is minimal. The review of pertinent literature found that the implementation of product certification procedures for recycled C&D waste materials is hindered by several obstacles. Figure 10 shows that these include the process being costly, the costs being currently unjustified, self-certification, the lack of alignment between RPC and sustainability rating systems, the operation of unreliable certifiers and a lack of collaboration.

A report by Equilibrium[6] indicated that, in Australia, PwRC is not independently validated through robust support testing. Product certification is cost-intensive, and with little uptake and a lack of opportunities to use these products, justification of the expense of certifying these products is difficult. Ghaffar (2019)[7] indicated that mandatory product certification expenses in the European Union (EU) add to the price of the material and may negate any cost savings from reusing it.

Self-certification is also utilised to establish the quality of PwRC. Recyclers and providers of these materials often perform self-certification. Although it is less expensive, the certification does not assure end-users that they may safely utilise PwRC.

[4] Park J and Tucker R (2017) 'Overcoming barriers to the reuse of construction waste material in Australia: A review of the literature', International Journal of Construction Management, 17(3), pp.228-237.

[5] WSP Environmental and TRL Ltd. (2005) Evaluating options for declaring recycled content in construction products and projects. The Waste & Resources Action Programme. https://bit.ly/3OPK0NK

[6] Equilibrium (2019) Review of standards and specifications for recycled content products. Department of the Environment and Energy, Melbourne, Australia. https://bit.ly/3HROgdz

[7] Ghaffar S (2019) How we can recycle more buildings. The Conversation. Available at https://bit.ly/3R1iyyu

Figure 10. Primary Barriers to Using RPC for Procurement of PwRC

Key Drivers of the Application of RPC: Literature Review

Six categories of RPC enablers have been identified following a comprehensive literature review. These classifications are illustrated in Figure 11. Effective quality monitoring and certification of recycled products by suppliers is required to instill and maintain stakeholder trust in the materials. However, this must be accompanied by more vigorous government action in the form of legislation and standardisation.[8] Governments at all levels should also initiate promotional activities via the media to change the general public's attitudes towards recycled products. They could also organise regular training on changing industry stakeholders' attitudes.[9]

Furthermore, a contractual obligation or otherwise a client requirement to use certified recycled products is another enabler for the implementation of RPC.[5] Currently, in the EU, it is illegal to use recycled content in construction materials that are not certified,[7] which has resulted in the more frequent uptake of these programs in construction projects across the European territory. According to a report by WSP,[5] the advantages of mandatory RPC include the eradication of rogue traders, greater confidence in the data provided for all parties, less room for manipulation and the credibility required to make the RPC valuable.

Figure 11. Primary Enablers of Using RPC for Procurement of PwRC

[8] Silva, R.V., De Brito, J. and Dhir, R.K (2017). Availability and processing of recycled aggregates within the construction and demolition supply chain: A review, Journal of Cleaner Production, 143, pp.598-614.

[9] Bao Z and Lu W (2020) Developing efficient circularity for construction and demolition waste management in fast emerging economies: Lessons learned from Shenzhen, China, Science of the Total Environment, 724, p.138264.

Case Study Analysis: Awareness, Support and Perceptions

Among the four case studies, only one project (Case Study 3, Tonkin Gap Project and Associated Works) employed some sort of RPC to procure PwRC. The process of certification was done internally by the client organisation. In Case Study 2, the client organisation conducted several tests (for example, UV stability, fire rating, durability impact testing) to ensure that PwRC used in the project would have the quality that is acceptable to Victoria's Department of Transport and Planning. In Case Study 3, the certification was developed under the Roads to Reuse initiative and is currently used in several WA government projects to ensure the quality compliance and safety of PwRC applications in state road infrastructures.

In terms of stakeholders' awareness, the findings suggest that 9/16 interviewees were aware of the existence of such certifications for PwRC (highlighted in green in Figure 12), whereas 7/16 interviewees indicated they had no or limited prior knowledge about their application in the industry (highlighted in red in Figure 12).

A similar trend was also observed in the way that the respondents provided their responses with respect to their support of their application to construction projects in Australia. Meaning that only 9/16 interviewees had positive attitudes towards their application in the industry. The stakeholders' awareness of RPC and the support for its application varied among the key stakeholder groups. As illustrated in Figure 12, individuals from the builder stakeholder group had the least prior knowledge of the existence and application of RPC for PwRC. In terms of the support for the application of this certification scheme, all individuals representing the client organisation in the case studies indicated they support using RPC in construction projects. Conversely, the PwRC supplier group had the highest level of reluctance to apply for these certifications.

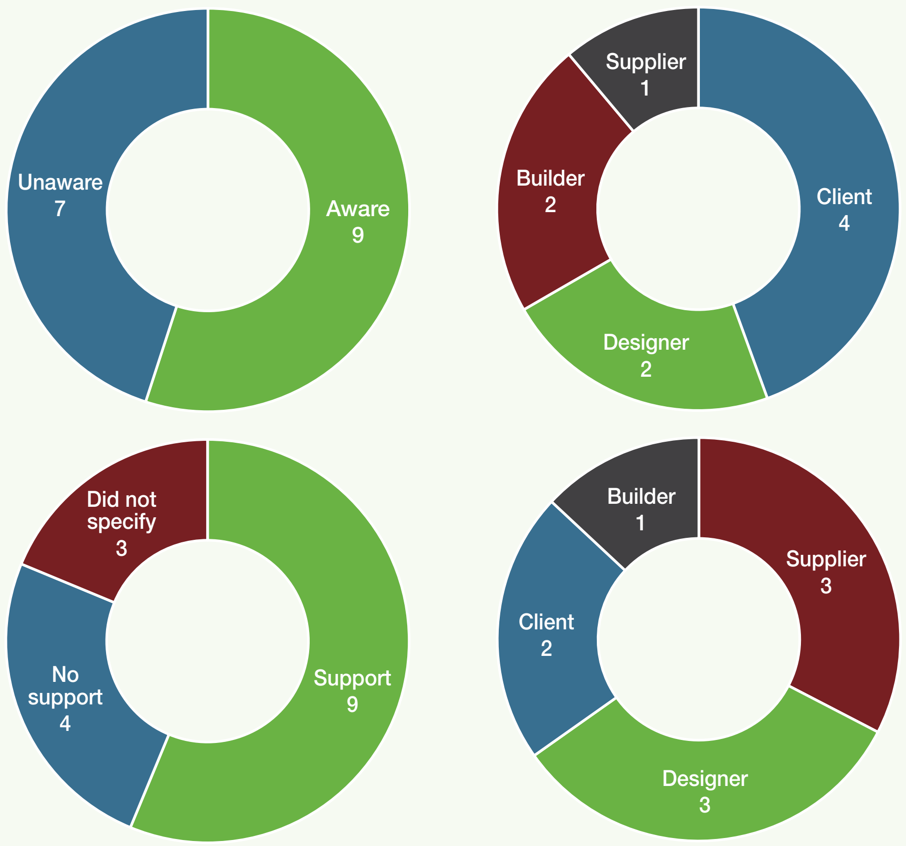

Figure 12. Interviewees' Perceptions of RPC (Awareness and Support for RPC Application)

Clockwise from top left: Awareness of the existence of RPC; Awareness of RPC existence by the stakeholder groups; Support for the utilisation of RPC by stakeholder groups; Support for the utilisation of RPC

Case Study Analysis: Main Benefits of RPC Application

Those who supported the use of RPC in this study indicated six benefits emerging from their application. These benefits, as illustrated in Figure 13, are strongly interconnected. For instance, by assuring safety and quality control, the purchasing organisations are able to reduce the risk of PwRC, which in turn generates demand for these materials, and thus minimises C&D waste disposal.

1. Reduce the risk of PwRC application
2. Ensure safety and quality control
3. Build confidence among buyers
4. Ensure PwRC meets product specifications
5. Generate demand for PwRC
6. Minimise waste disposal

Figure 13. Main Benefits of RPC Application in the Built Environment Sector

4.0 Recycled Product Certification Programs (cont'd)

Case Study Analysis: Main Limitations of RPC Application

As indicated above, not all stakeholders expressed their support for using RPC in the sector. Even some of those who supported RPC application or had limited to no prior knowledge of it referred to the limitations of relevant applications. As shown in Figure 14, stakeholders highlighted seven major limitations relating to various aspects of RPC applications. Three of these limitations were related to the schemes per se: the abundance of RPCs with different requirements (Limit #2), lack of transparency in their requirements (Limit #3) and limited applicability for certain products (Limit #4).

1. Unjustified application in presence of product specifications
2. Abundance of RPCs with different requirements
3. Lack of transparency in RPC process and testing criteria
4. Limited applicability for certain products
5. Unjustified cost
6. Certifiers' poor performance
7. Recyclers' limited capacity to be certified

Figure 14. Main Limitations of RPC Application in the Built Environment Sector

Operation of an RPC Issuing Organisation: A Case Study Analysis

To analyse the operation of RPC organisations that issue RPC for PwRC, a case study approach was used. The case study selected for this analysis is an Australian-based organisation that has been in operation for the last 10 years. The organisation offers end-product certifications that help material manufacturers to demonstrate the fulfilment of requirements specified by different sustainability rating tools and product specifications. The primary pricing mechanism in this organisation is on a quote-by-quote basis. Despite having the price structure for any of the certification types, the cost of certification in this organisation is a function of various factors, as shown in Figure 15.

The interviewee in this case study that represented the organisation mentioned that the main stakeholders who influence the utilisation of RPC are governments (at all levels), leading companies, clients and developers, and the architecture and design community, who are keen to use sustainability as their selling marketing point. Figure 16 summarises the main findings of the interview regarding the main drivers, strategies and barriers for using RPC in the construction industry.

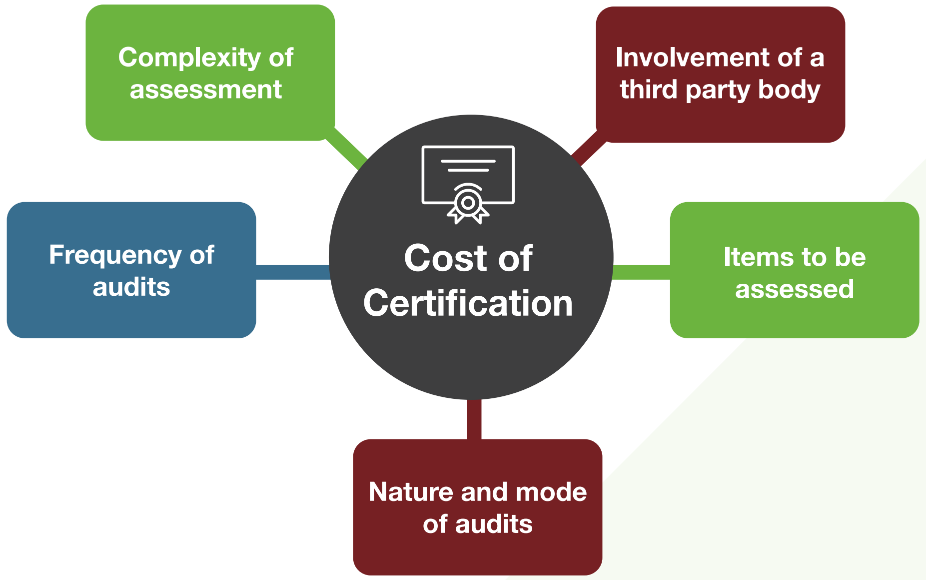

Figure 15. Factors that Determine the Cost of RPC

Stakeholders	Drivers	Strategies	Barriers
• Governments (at all levels) • Leading companies • Clients and developers • Architecture and design community	• Increase in the awareness of circular economy • Recent attempts to combat the impacts of climate change • Change in the Australian political landscape • Motivation of the public agencies to enforce policies that require the use of PwRC • Improve biodiversity and nature positive outcomes	• Mandatory application • Incorporate RPC cost in the marketing budget • Change in policies in favour of the RPC application • Make it a priority in rating tools	• Conflicting commercial interest • Lack of consideration of RPC as a priority

Figure 16. Summary of the Main Interview Findings

A CE offers a framework to address the adverse effects of the business-as-usual model of the construction industry. A CE can be defined as an economic system that replaces the end-of-life (EoL) concept by reducing, reusing, recycling and recovering materials.[10] The redefinition of the EoL concept in a CE is a key factor in decoupling economic growth and resource consumption.[11] The Ellen MacArthur Foundation (EMF) has established three main principles of a CE: (i) eliminate waste and pollution, (ii) circulate products and materials and (iii) regenerate nature.[12] A CE in the built environment aims to use sustainable materials, to keep the value of materials, to increase material recovery once these have reached their EoL and to minimise waste.[13,14]

Through CE practices embedded with DfZw and DfR principles, much of the C&D waste generation could be avoided or at least recirculated within the construction sector supply chain. Evidence shows that there may be a positive correlation between new construction, waste recovery and energy consumption. Although there is no clear academic consensus on the environmental benefits of using PwRC, some studies have shown, through life-cycle analysis of either costs or energy, that the use of PwRC and prefabricated components in new construction has several positive impacts. Some benefits include greenhouse gas emissions reduction, non-renewable energy savings, and less water consumption and hazardous waste generation.[15,16,17]

Review of Published Literature

Based on the title, abstract and keywords of all 115 articles reviewed, the articles were grouped into eight specific focus areas after completing multiple iterations of identification, selection and regrouping of research focus and scope covered in the articles (Table 2).

Table 2. Broader Scope, Specific Focus and Key Elements Covered in the Selected Articles

Broader Scope	Specific Focus	Number of Articles	Key Elements Covered in the Articles
Circularity Practices	CE/zero waste/no waste	19	Zero waste and CE principles, understanding of key barriers and opportunities in the transition to a CE-built environment
	Design for deconstruction (DfD)/disassembly	12	The application of CE and DfZw principles such as DfD or deconstruction. Design for reusability and adaptability and the opportunities for reusing the entire building by relocating and adaptive reuse
	Reuse of building, elements, materials	11	The opportunities for reusing construction materials such as aggregates and timber, and reusing building elements/components such as steel frames and steel beams/columns
Resource Management	Recycling/resource management	21	Waste resource management from the point of minimisation, recycling and recovery of resources from waste, including post-disaster events and the relevant regulatory policies
Innovation and Optimisation	Digital technology	14	Digitisation and application of innovative technologies such as Building Information Modelling (BIM), digital material bank, material passport and cloud computing to enable data-driven decisions are the key focus of digital innovation
	Construction innovation	13	The recent innovation in construction technologies such as offsite/modular construction, prefabrication and green construction materials using alternative building materials sourced from recycled components seem to be the key areas covered by the articles
	Project/supply chain optimisation	11	Project optimisation through innovative approaches such as the integration of a client–designer interface and introducing an early contractor's involvement in the design phase to minimise waste, better manage materials and optimise productivity
Sustainability Assessment	Measurement	14	Measuring impacts of current practices and the sustainability benefits and performance in the context of sustainability priorities

[10] Kirchherr J, Reike D and Hekkert M (2017) 'Conceptualizing the circular economy: An analysis of 114 definitions', *Resources, Conservation and Recycling*, 2017. 127: p. 221-232.
[11] Gomes da Silva FJ and Gouveia RM (2019) *Cleaner Production: Toward a Better Future.* Cham: Springer International Publishing AG.
[12] Ellen MacArthur Foundation. What Is a Circular Economy? Retrieved March 2023. Available at: https://bit.ly/3XmaUka
[13] Dams B et al. (2021) 'A circular construction evaluation framework to promote designing for disassembly and adaptability', *Journal of Cleaner Production*, 316: p.128122
[14] Norouzi M et al. (2021) 'Circular economy in the building and construction sector: A scientific evolution analysis', *Journal of Building Engineering*, 44: p. 102704.
[15] Lee JC et al. (2010) 'Quantitative assessment of environmental and economic benefits of recycled materials in highway construction', *Transportation Research Record*, 2158(1): p.138-142.
[16] Hong J et al. (2016) 'Life-cycle energy analysis of prefabricated building components: An input–output-based hybrid model', *Journal of Cleaner Production*, 112: p. 2198-2207.
[17] Partnership for Action on Green Economy (2022) India on the Path to Create a Centre of Excellence on Circular Economy. Retrieved 15 January 2023. Available at: https://bit.ly/3x9thhA

CE Guidelines for the Construction and Infrastructure Industry

Analysis of both scholarly and grey literature led to the development of guidelines for implementing CE practices in the construction and infrastructure industry. The guidelines were based on the broader scopes identified during the literature review. Table 3 shows an overview of the developed guidelines. Performance sustainability measurements in the form of either qualitative or quantitative key performance indicators (KPIs) are provided for the strategies shown in the table. In addition, each strategy was evaluated using a heatmap according to the level of alignment with the Ellen MacArthur Foundation (EMF) CE principles. The levels of alignment are high, medium and low. A high alignment means that the strategy could contribute greatly to achieving the desired outcomes of each EMF CE principle; a medium alignment means a contribution to a certain extent; and a low level means a low contribution.

Table 3. CE Guidelines for the Built Environment and Alignment with the EMF CE Principles

Broader Scope	Strategy	KPI	Alignment with EMF CE Principles		
			Design-out-Waste and Pollution	Keep Products and Materials in Use	Regenerate Natural Systems
Circulatory Practices	1. CE procurement	Both qualitative (yes/no) and quantitative (%) of the PwRC	High	High	Medium
	2. Design for Deconstruction (DfD)	Disassembly potential rating	High	Medium	Low
	3. Design for flexibility and adaptability	Adaptability and flexibility rating. Intensity use=proportion of the building's total usable area/gross floor area (GFA)	Medium	High	Low
	4. Design for long life	Both qualitative (yes/no) and quantitative whole life-cycle cost [$/m2/yr]	High	High	Low
	5. Eliminate building components	Material use intensity per functional unit (kg/unit/year)	High	Low	Low
	6. Reuse building/ building elements	Reused floor area (% of total GFA) or building component reuse in %	High	High	Medium
	7. Restore and regenerate	Soil sealing factor and/or compensatory measures (rainwater management, green roofs)	Low	Low	High
	8. Design out hazardous/pollutant materials	Environmental impact cost [$/m2/year]	Medium	Low	High
	9. Climate resilient design	Embodied carbon intensity [kgCO2 eq/m2/year]	Medium	Low	High
	10. Sharing economy/shared space	Provision of the shared economy (yes/no) or % of shared space	Medium	High	Low
Resource Management	11. Waste prevention on the construction site	Diversion rate from landfill (%)	Medium	High	Low
	12. Material/ component recycling	Proportion (mass/unit of reference) of secondary materials installed in the building. GFA could serve as the unit of reference	High	High	Low
Innovation and Optimisation	13. Use of digital technology (e.g. material passports)	The proportion of building components or traceable materials in %	Medium	Medium	Low
	14. Construction innovation (e.g. modular construction)	Proportion modular and/or offsite construction in %	Medium	Low	Medium
	15. Green supply chain (e.g. use of bio-based materials)	Local vs overseas/sustainably sourced (%)	High	Low	High
	16. Use and integration of sustainable technology	Energy demand from renewable sources (%), energy storage capacity (kWh/time), microgrid options, etc.	High	Low	Medium

Coordinated knowledge-sharing and education initiatives should be implemented to address the needs of governments, businesses and individuals, and to encourage the redesign, reuse, repair, resource recovery, recycling and reprocessing of products. However, increasing concerns related to the quality, performance characteristics and durability of PwRC are influencing the mainstreaming of such products in the Australian construction industry.

To ensure increased uptake, behavioural and attitudinal changes are important for the acceptance of PwRC, as well as managing construction waste that is generated during the construction and demolition stages of the project. Within the project, Objective 4 focused on developing stakeholder-guided behaviour change strategies through a co-design/co-created educational program for the construction industry.

Target Audience

The capacity-building initiative was aimed at individuals involved in management and decision-making for solid waste systems which recycle and dispose of waste generated as a result of the construction, deconstruction, renovation and demolition of buildings and structures. The intended audience includes architects, design and structure engineers and construction site personnel.

The program was pilot-tested with one infrastructure sector industry partner and one building sector industry partner (that is, Main Roads WA and the WA Department of Communities). The training effectiveness was evaluated through a survey based on the Kirkpatrick model.[18] The summary of key content in the training packages is provided in Table 4.

Table 4. Summary of Proposed Training Packages (to be further discussed with core industry partners)

Key Content	Key Projects
• CE: opportunities to reduce waste disposal across the supply chain (with a specific focus on materials including timber, glass, concrete, steel and brick) • Creation and stimulation of end markets for C&D waste • Regulations and their application in practice in different jurisdictions governing C&D waste management	Project 1.65 Project 1.75
• Identifying barriers and enablers influencing the use of products with recycled content (Objective 1) • Independent certification program for products with recycled content (Objective 2) • CE guidelines (Objective 3)	Project 1.85

Intended Outcomes for Participants

- Identify environmental, economic and social impacts of C&D waste
- Understand the differences between CE versus linear economy
- Identify opportunities for creating a CE
- Describe the types of material and market opportunities
- Learn about opportunities for creating a CE

[18] Kirkpatrick, DL (1959) 'Techniques for evaluating training programs', *Journal of the American Society of Training Directors*, 13, 3–9.

6.0 An Educational Program for the Construction Industry (cont'd)

Key Findings

This section presents the post-survey findings from two training sessions conducted on 9 March 2023.

Training Session 1 – Industry partner: Main Roads WA

Table 5 presents a summary of the survey findings. A total of 21 participants responded to the survey questions. According to the results, training participants identified responsible consumption and production as the most relevant Sustainable Development Goals (SDGs) for their work, with reuse of material as the most important aspect of a CE. Most participants agreed that landfill levies encourage recycling and resource recovery, while identifying concrete as a material with the most potential for creating a CE in their organisation.

Table 5. Summary of the Survey Findings

Survey Questions	Results
1. Which of the following SDGs is the most relevant for your work?	
Industry innovation and infrastructure [SDG 9]	28% (6)
Sustainable cities and communities [SGD 11]	19% (4)
Responsible consumption and production [SDG 12]	42% (9)
Climate action [SDG 13]	9% (2)
2. Which aspect of a CE is most important to you?	
Less landfill waste	4% (1)
Reuse of material	54% (12)
Environmental benefits	40% (9)
3. Do landfill levies encourage recycling and resource recovery?	
Yes	61% (13)
No	38% (8)
4. Which C&D waste material has the most potential for creating a CE in your organisation?	
Concrete	80% (17)
Glass	0% (0)
Plastic	4% (1)
Rubber	14% (3)

Overview of participants and training expectations

Overall, there were 21 participants including material engineers, project managers and construction managers. A total of 12 participants (57 per cent) responded to the post-training survey. One of the key objectives of this study was to determine if the training content met participant expectations. According to the survey results, 10 participants said 'Yes' and two participants said 'No' when asked if the training content met their expectations. One participant stated: *'The training course is adaptable and relevant for MRWA staff.'* Another participant stated that the *'audience mostly aware of opportunities and the existing problem are the current blockages to these opportunities'*. As shown in Figure 17, nearly 92 per cent (n=11) of the participants either strongly agreed or agreed with the statement that the material was presented in a clearly organised way. One participant disagreed with this statement. A total of 11 participants strongly agreed (25 per cent) or agreed (67 per cent) that the content was presented in an interesting way. Out of 12 participants, 11 participants strongly agreed (33 per cent) or agreed (58 per cent) that the presenters showed good knowledge of the subject matter.

A total of 11 participants strongly agreed (25 per cent) or agreed (67 per cent) that they were satisfied with the quality of the content and all participants agreed that the mix between PowerPoint slides and activities was suitable. Out of 12 survey participants, 10 participants said they learned something new. Out of the total participants, 10 participants said that the course was easy to apply to their work areas, while two participants said it was not. For example, one participant described that *'the next steps in the role are to address the barriers to the opportunities, not to identify the opportunities or problem statement'*. The participants shared detailed feedback on key learnings of the training course. One participant specifically stated that *'[t]he training course is adaptable and relevant for MRWA staff'*.

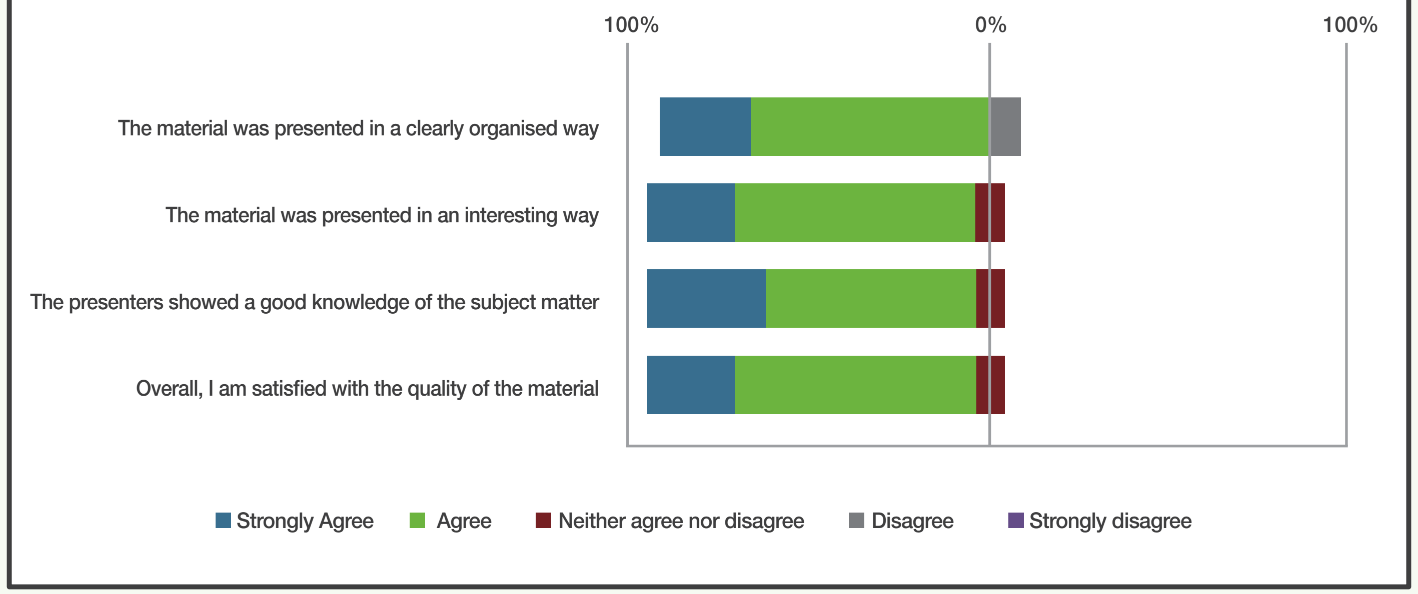

Figure 17. Main Roads WA Participant Responses on Quality of the Training

Training Session 2 – Industry partner: WA Department of Communities

Table 6 presents a summary of the survey findings. A total of 21 participants responded to the survey questions. According to the results, training participants identified sustainable cities and communities as the most relevant SDGs for their work, with reuse of material as the most important aspect of a CE. Most participants agreed that landfill levies encourage recycling and resource recovery, while identifying brick as a material with the most potential for creating a CE in their organisation.

Table 6. Summary of the Survey Findings

Survey Questions	Results
1. Which of the following SDGs is the most relevant for your work?	
Industry innovation and infrastructure [SDG 9]	29% (6)
Sustainable cities and communities [SGD 11]	52% (11)
Responsible consumption and production [SDG 12]	10% (2)
Climate action [SDG 13]	10% (2)
2. Which aspect of a CE is most important to you?	
Less landfill waste	19% (4)
Reuse of material	57% (12)
Environmental benefits	24% (5)
3. Do landfill levies encourage recycling and resource recovery?	
Yes	86% (18)
No	14% (3)
4. Which C&D waste material has the most potential for creating a CE in your organisation?	
Concrete	33% (5)
Brick	53% (8)
Steel	13% (2)
Glass	0% (0)

Overview of participants and training expectations

Overall, there were 27 participants including project managers, construction managers and administrative staff. A total of 13 participants (48 per cent) responded to the post-training survey. One of the key objectives of this study was to determine if the training content met participant expectations. According to the survey results, 12 participants said 'Yes' and one participant said 'No' when asked if the training content met their expectations. Participants described a range of expectations related to education and awareness, understanding the CE concept, material opportunities and case study examples. In addition to the above training expectations, one participant suggested that the information was at a high level, and *'would have liked some detailed case studies with lessons learned'*. As shown in Figure 18, all 13 participants either strongly agreed (46 per cent) or agreed (54 per cent) to the statement that the material was presented in a clearly organised way. A total of 12 participants either strongly agreed (46 per cent) or agreed (46 per cent) that the content was presented in an interesting way. One participant neither agreed nor disagreed (8 per cent) with this statement.

All 13 participants either strongly agreed (39 per cent) or agreed (62 per cent) that the presenters showed a good knowledge of the subject matter. Out of the 13 participants, 11 participants either strongly agreed (46 per cent) or agreed (39 per cent) that they were satisfied with the quality of the material. Two participants neither agreed nor disagreed (15 per cent) with this statement. All 13 participants agreed that the mix between PowerPoint slides and activities was suitable. For example, one participant said, *'I liked the break with the little interactions to break up the course. That was more refreshing than just listening to talking heads'*, and another participant said that the *'content and pace was perfect'*. All 13 participants stated that they learned something new. Out of the total, 12 participants said the course was easy to apply to their work areas.

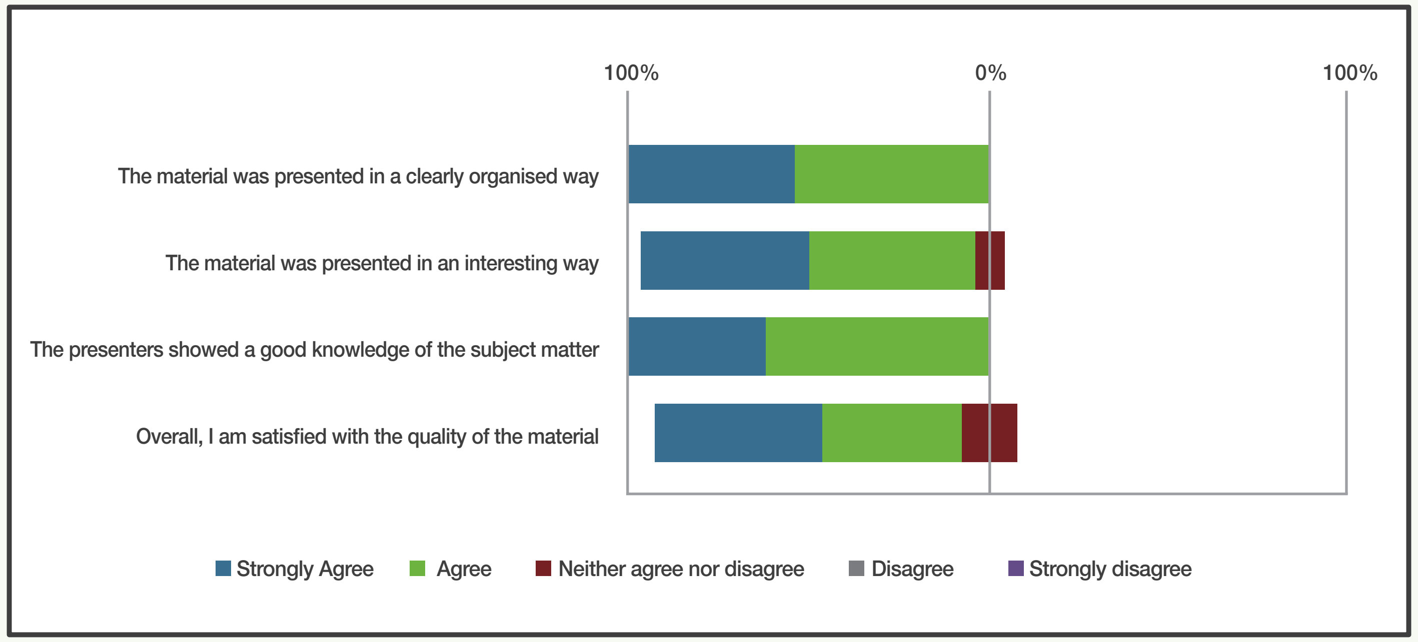

Figure 18. WA Department of Communities Participant Responses on Quality of the Training

7.0 Conclusion

This research attempted to contribute to developing an understanding of the sustainable application of PwRC in the Australian construction industry. The research shows that many barriers are currently hindering the application of these resources in construction projects. These barriers seem to be context-specific, and their impact's likelihood and severity are hinged on a series of external and internal factors.

Furthermore, the study showed that individuals from different stakeholder groups have various motives for and understanding of barriers to using PwRC. Therefore, any changes required to improve the current climate in this space need to acknowledge the differences in perceptions of various stakeholders.

The main conclusion of this study, which is supported by case study analyses, is to prioritise the early engagement of key stakeholders in planning construction projects where PwRC is to be used. The key stakeholders, however, need to be motivated and informed to ensure that their ultimate commitment and collaboration results in the successful application of PwRC in the industry.

Federal and state governments are in the best position to provide such motivations through their policymaking power. Furthermore, their continuous leadership in this space will bring about a series of fundamental changes to the industry's ecosystem that produce long-term positive outcomes.

Photography by Sergio Souza (Source: Pexels)

8.0 Moving Forward

The study identified a suite of recommendations and strategies to tackle the barriers to using PwRC in the construction industry (Table 7). These recommendations form the basis for future policy reforms and structural changes that the industry needs to adopt to optimise the utilisation of PwRC and for driving a CE in the Australian context.

Research institutes have a pivotal role in determining the real impact of these recommendations on the current and future of the industry supply chains. Furthermore, these institutes, in collaboration with the industry associations establishing effective training courses for the stakeholders, can enable informed decisions in favour of the PwRC application. For instance, the training package that was developed in this study can be presented to members of associations and industry peak bodies that are involved in the construction industry. Such collaborations can also be extended to developing guidelines that steer a specific stakeholder group towards the optimised utilisation of PwRC in the industry. The CE design guidelines that were developed in this research are a clear example of how guidelines can be effective and informative in driving change for the better.

Lastly, those who are involved in managing C&D waste need to play a more active role to unleash the potential of existing tools, such as RPC, that may prove useful in confidence-building and encouraging the increased uptake of PwRC in the industry. Such an effort, in the mid-term, may result in addressing some of the limitations of the reasonable application of these tools.

Table 7. Recommendations: Next Steps

	Literature Review	Case Study Analysis	
Optimal Utilisation of PwRC	1. Increase community awareness and education on PwRC	6. Education, investigation and demonstration activities	13. Strong support from key stakeholders
	2. Develop supportive regulations, policies and specifications	7. Effective project management planning	14. Developing logistic capacity across supply chain to increase PwRC application
	3. Enable sustainability rating programs	8. Effective project contract development	15. Financial incentives
	4. Promote using RPC	9. Revising regulations in favour of PwRC utilisation	16. Mandating utilisation of PwRC
	5. Advocate targeted technologies and innovative practices	10. Early involvement of key stakeholders	17. Sharing the risk of using PwRC
		11. Effective material audits and testing	18. Sustainable supply of quality PwRC
		12. Setting clear expectations and understanding of PwRC application	
	Literature Review	**Case Study Analysis**	
Enhance the Effectiveness of RPC	1. Government intervention through robust legislation and standardisation	7. Increase in the awareness of CE	
	2. Government-led promotional activities to change the general public's attitudes	8. Recent attempts to combat the impacts of climate change	
	3. Education is required to change industry stakeholders' attitudes	9. Change in the Australian political landscape	
	4. Obligatory utilisation of RPC in public construction projects	10. Motivation of the public agencies to enforce policies that require the use of PwRC	
	5. Availability of more qualified material engineers to reduce the cost of certification	11. Improve biodiversity and nature positive outcomes	
	6. Increase RPC adoption with the development of simple yet effective procedures		
	Literature Review		
Circular Design	1. CE procurement to ensure products with recycling content	5. Restore and regenerate human and natural systems	9. Use of digital technology (BIM, AI, material passports, digital twins, etc)
	2. DfD and disassembly	6. Design out hazardous/pollutant materials	10. Construction innovation (prefabrication, modular design)
	3. Design for flexibility and adaptability to increase convertibility	7. Climate resilient design to minimise embodied carbon footprint of materials	11. Use of locally sourced bio-based materials as part of green supply chain
	4. Design for longevity and product's long service life	8. Sharing economy/shared space: intensify use of materials	12. Use of sustainable technology (passive house design, grid compatibility, use renewable sources)

Find out more:

Project webpages (including link to YouTube video):
Enhancing the Use of Products with Recycled Contents in the Australian Construction Industry – Final Industry Report
https://sbenrc.com.au/research-programs/1-85/

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