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Circular Economy-Related Strategies to Minimise Construction and Demolition Waste Generation in Australian Construction Projects

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Abstract: The construction industry in Australia generates a significant amount of construction and demolition (C&D) waste, necessitating better waste management (WM) practices. This research addresses this issue by investigating CE strategies aimed at minimising C&D waste in Australian construction projects (CPs). Utilising a qualitative approach, the study is based on 20 interviews and four case studies of commercial CPs, analysed through NVivo content analysis. The findings emphasise the need to integrate CE strategies at every CP stage. In the pre-design phase, setting sustainable objectives and engaging stakeholders early is crucial for aligning goals to reduce C&D waste. The tendering process benefits from incorporating WM into contracts, demonstrating early commitment to sustainability. The design phase, through Building Information Modelling and designing for disassembly, offers substantial waste-reduction opportunities. Modular and prefabricated components during the construction phase enhance material reuse and recycling. Operational strategies like regular maintenance and retrofitting extend material lifespan, while selective demolition and digital cataloguing at the end-of-life phase enable efficient material recovery. This highlights the essential roles of policy, technology, and stakeholder collaboration in advancing CE practices, providing practical insights for construction professionals and policymakers to implement CE-related strategies in CPs. The research concludes that adopting CE strategies can lead to significant reductions in C&D waste and improved sustainability in the construction sector.

Keywords: circular economy (CE); construction projects (CPs); construction and demolition (C&D) waste; strategies; waste management (WM)

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1. Introduction

The construction industry (CI) is a significant contributor to global economic development and a major source of negative environmental impacts due to its substantial resource consumption and waste generation [1]. When it comes to the Australian context, construction and demolition (C&D) waste accounted for 38% of total waste generation (25.2 million tonnes) in 2021 [2]. Even though waste management (WM) practices have been proposed and applied for decades, a high rate of C&D waste generation, with a relatively high landfill rate, continues to prevail in the Australian CI [2].

In recent years, the concept of a circular economy (CE) has gained wider attention as a sustainable alternative to the traditional linear economy [3]. A circular economy emphasises the efficient use of resources, waste minimisation, and the maximisation of resource utility over the lifecycle of products and materials [4]. Despite its growing recognition, integrating CE-related strategies into WM practices in construction projects (CPs) remains an underexplored area, particularly in the context of Australian CPs.

Thus, this research aims to address this gap by investigating the application of CE strategies in WM within the construction industry. Specifically, its goals focus on identifying effective CE-based strategies and their potential to minimise C&D waste in Australian construction projects. By investigating these CE-based strategies, the research can contribute to providing practical insights and recommendations for construction professionals and policymakers to enhance waste-management practices.

2. Literature Review on Strategies to Minimise Construction- and Demolition Waste Generation in Construction Projects

The CE concept has recently gained wider attention among academics, businesses, and governments [5]. Many researchers advocate it as an alternative model to transition from a linear system to a more circular one, characterised by a make–use–recreate approach [6,7]. Circular economy (CE) is "restorative and regenerative by design and aims to keep products, components, and materials at their highest utility and value at all times, distinguishing between technical and biological cycles" [8] (p. 19). Twelve main types of CE principles have been highlighted, including refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, recovery, regenerate, and remine [7]. These principles are often combined with different orders and hierarchies of various categories, while some have been implemented for many years [5].

Furthermore, stakeholders should treat C&D waste as a resource continuously reused within an integrated and closed-loop system rather than as a residual product [9]. The CE approach seeks to design-out waste and pollution, extend product and material life, and regenerate natural systems, thereby encapsulating holistic C&D WM strategies [10]. Thus, applying C&D WM strategies should not be limited to the construction or demolition phases but should consider the entire life cycle of building projects [11,12]. This section critically reviews the existing literature on various building project life cycle (BPLC) stages, outlining strategies for integrating C&D WM into each stage, and focusing on the following stages: the pre-design, design, tendering and contract, construction, operation, and end-of-life stages, as shown in Table 1.

Table 1. C&D WM strategies in building project life-cycle stages.

BPLC Stage		C&D WM Strategy	Reference
Pre-design		• Setting sustainable goals • Early integration of WM objectives • Conducting feasibility studies to identify C&D WM strategies • Engaging stakeholders to ensure a common understanding of C&D WM goals and expectations • Using life-cycle assessment (LCA) tools to evaluate the environmental impact of different project alternatives and support more sustainable decision-making	[12–14]
Design		• Optimising material usage • Using Building Information Modelling (BIM) to assess waste generation potentials, optimise material usage, and identify opportunities for reuse • Incorporating sustainable materials and systems • Designing for deconstruction	[15–19]
Tendering and Contract	Tendering	• Green procurement policies • Incorporating C&D WM requirements in tender documents • Assessing contractors' and suppliers' capacity and experience in minimising C&D waste	[20–22]
	Contract	• Incorporating C&D WM clauses • Developing WM plans • Performance incentives to encourage WM targets to be exceeded	[14,23]
Construction		• Implementing waste reduction and recycling measures • Employing modular and prefabricated components • Regular waste monitoring and reporting	[16,24–26]
Operation		• Regular maintenance and retrofitting • Facility management practices to prioritise the use of sustainable materials and resource-efficient processes • Waste management plans for the operational phase	[27–29]
End of life		• Employing selective demolition techniques to reuse materials • Applying reverse logistics systems • Partnering with recycling facilities to promote resource efficiency and waste diversion from landfills	[29,30]

The pre-design phase in the BPLC is pivotal, setting project objectives, constraints, and requirements. This stage shapes the project's environmental outlook [12]. A critical component is framing sustainable goals, and emphasising waste reduction and resource efficiency [6]. Integrating WM objectives early, such as the three Rs—reduce, reuse, recycle—can enhance C&D WM across the project [13]. Feasibility studies enable early C&D WM strategy identification, considering site selection, material efficiency, and nearby WM facilities [12]. Engaging stakeholders like clients, designers, and authorities ensures alignment on WM goals, fostering co-operative approaches to challenges [14]. Incorporating LCA tools at this stage assists in assessing environmental impacts and guiding waste and material decisions throughout the BPLC [12].

The design stage is pivotal for C&D WM, enabling material optimisation, waste minimisation, and the integration of sustainable materials and systems [15,18]. This phase allows for the detailed planning and incorporation of C&D WM strategies, like efficient material use and recycling [15]. A vital tool supporting these objectives is BIM. It enables designers to evaluate waste potential, optimise material consumption, and spot reuse opportunities [18]. It can also simulate deconstruction scenarios, guiding the creation of components that support deconstruction and material recovery at a building's end of life [16]. Beyond BIM, designers can weave sustainable materials and systems into their blueprints [17,19]. Such materials and systems, like green concrete, low-embodied energy materials, and renewable energy systems boost a building's environmental efficacy and curtail waste [31].

The tendering stage involves soliciting bids from contractors and suppliers to execute the project. This stage is critical for selecting environmentally responsible contractors and suppliers as it provides an opportunity to ensure that C&D WM strategies and targets are integrated into the project from the outset. Green procurement policies can be implemented to prioritise the selection of suppliers with strong environmental credentials [21]. These policies may include specific requirements for suppliers to demonstrate their commitment to waste reduction, recycling, and environmentally responsible practices. Furthermore, tender documents should incorporate C&D WM requirements, such as waste-reduction targets, recycling expectations, and WM plans [22]. During the tender evaluation process, assessing the contractors' and suppliers' capacity and experience in managing C&D waste is essential. This can be achieved by evaluating their track records, environmental certifications, and proposed WM strategies [20]. By prioritising environmentally responsible contractors and suppliers during the tendering stage, projects can ensure a strong foundation for effective C&D WM throughout the BPLC.

The contract stage is characterised by the negotiation and formalisation of agreements between the client and the selected contractors and suppliers. This stage provides a critical opportunity to ensure that C&D WM strategies and targets are legally binding and enforceable. To this end, contracts should incorporate specific clauses related to C&D WM, such as waste reduction and recycling targets, WM plan development and implementation, and regular waste monitoring and reporting [14]. These clauses can establish clear expectations and responsibilities for all parties involved in the project, ensuring a shared commitment to WM objectives. Furthermore, performance incentives can be integrated into contracts to encourage contractors to exceed WM targets, fostering a culture of continuous improvement in CPs [23]. These incentives may include financial rewards or penalties [32,33], contract duration extensions [34], or preferential consideration for future projects. By incorporating C&D WM requirements and incentives into contracts, clients can promote accountability and drive better environmental performance throughout the BPLC.

The construction stage is where most C&D waste is generated. Excess and residual materials from the C&D stage are often discarded and treated as waste, even if they could potentially be utilised [26]. This linear approach to WM, where materials are discarded and not used again, is not sustainable in the long run. During this stage, it is essential to implement waste reduction and recycling measures on sites to mitigate the environmental impact of construction activities [24]. Site WM practices, such as waste sorting, segregation, and recycling can enhance resource efficiency and divert waste from landfills [25]. By designing for deconstruction during the design stage, the potential for material recovery and reuse can be significantly improved at this stage [16]. Modular and prefabricated components can be employed to facilitate deconstruction and material recovery [35]. These components not only streamline the construction process but also make it easier to dismantle and reuse materials at the end of the building's life cycle. In addition to these strategies, regular waste monitoring and reporting can be implemented to track progress towards WM targets and identify areas for improvement [36]. This information can be used to inform adjustments to WM practices [37] and ensure ongoing compliance with contractual obligations [34].

During the operation stage, regular maintenance and retrofitting can extend the building's life cycle, thus minimising C&D waste generation [29]. Implementing facility management practices prioritising the use of sustainable materials and resource-efficient processes can improve C&D WM [27]. Additionally, developing and implementing WM plans for the operational phase can ensure the proper handling, disposal, and recycling of waste generated from maintenance and retrofitting activities [28]. By monitoring and reporting on WM performance during the operation stage, facility managers can identify opportunities for continuous improvement and ensure compliance with WM targets and regulations.

At the end-of-life stage, the focus shifts to deconstruction, material reuse, recovery, and recycling [30]. Selective demolition techniques that segregate materials aid recycling and support CE [29]. Proper co-ordination during deconstruction can retain the integrity of reusable materials, optimise recovery, and reduce waste. Reverse logistics, which entail collecting and transporting waste from sites to recycling centres, can bolster C&D WM, ensuring materials re-enter the production cycle [29]. Forming partnerships with local recycling centres and fostering markets for recycled materials enhances resource efficiency and reduces landfill waste [38]. Collaboration with these facilities ensures sustainable handling of recovered materials, offering a green end-of-life building solution.

3. Methods

Exploring the adoption of CE-related strategies in WM within CPs, this study employed a qualitative research approach, focusing on the impact of such practices on resource consumption and waste generation in the construction industry (CI). This investigation involved two data collection methods—preliminary interviews (PIs) and case studies (CSs)—to gather insights into the implementation of CE in WM in Australian CPs.

Initially, preliminary interviews were conducted to understand the transition from traditional linear methods to CE-focused practices in construction. These interviews provided critical insights into the motivations for adopting CE in Australian CPs, chosen for their ability to prompt detailed discussions while allowing for the exploration of new themes [39]. A total of 20 participants, including CE experts and professionals in the CI, were interviewed. These participants were categorised by their roles (e.g., consultant side, client side, government side, and contractor side), as detailed in Figure 1. The participants generally had significant experience in the CI, in years of duration ranging from 3 to 49, and experience in C&D WM/CE, in years of duration ranging from 2 to 15. This sample size was selected to achieve data saturation—a key consideration in qualitative studies [40].

After that, case studies were conducted to explore the practical application of CE principles in real CPs. These studies offered insights into the practical application of CE-based WM practices, enabling an understanding of these concepts in real-world settings [41]. Four case studies in Australia were chosen, each highlighting different aspects of CE implementation, as described in Table 2. The table provides valuable insights into the characteristics and management of these four case projects, highlighting the importance of sustainability, the diversity of participant roles, and the variability in project scale and duration.

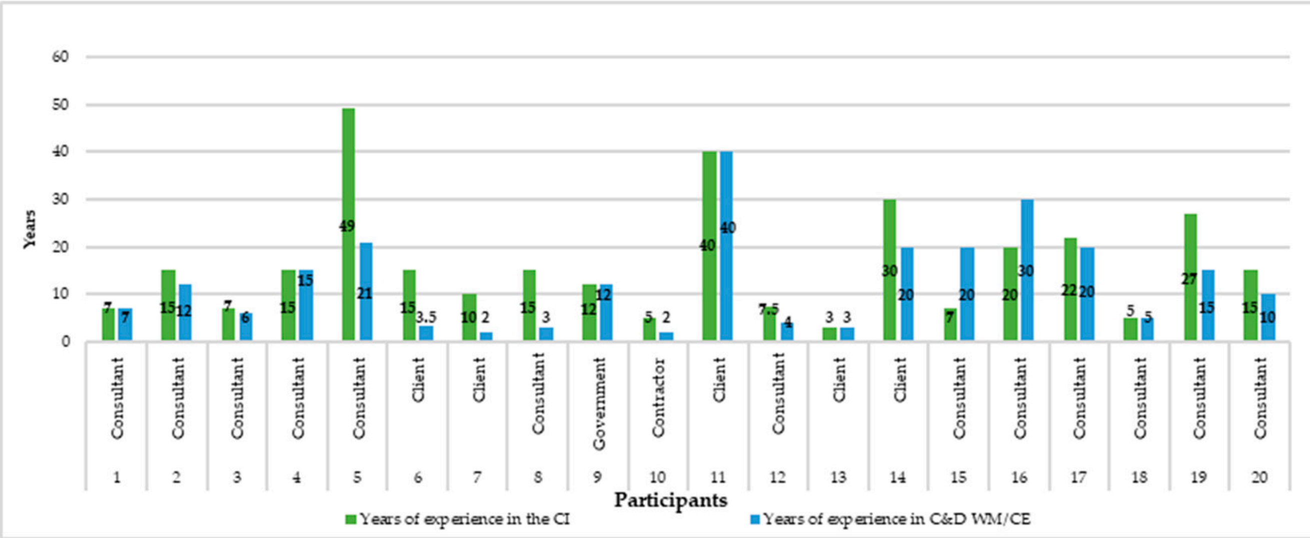


Figure 1. Description of participants in preliminary interviews.

Table 2. Brief description of case studies.

Information	**Case Study**			
	A	**B**	**C**	**D**
Construction type	Commercial	Commercial	Commercial	Commercial
Building type	Mixed-use commercial	Mixed-use commercial	Commercial residential	Mixed-use commercial
Number of storeys	6	49	6	8
Total gross floor area (sqm)	10,000	102,000	20,000	18,380
Total construction cost ($million)	81	900	100	110
Project duration	2020–2022	2016–2022	2020–2022	2018–2020
Procurement method	Design and Construct (D&C) [engaging through an Early Contractor Involvement arrangement]	D&C	D&C	D&C
Sustainability-related rating	Aiming to achieve: • A 6-Star Green Star (GS) Design & As Built v1.2 Rating • A 6-Star NABERS Energy Rating	• A 6-Star GS Office Design v3 Rating • A 6.5-Star NABERS Office-Base Building Energy Rating • A 4-Star NABERS Office-Base Building Water Rating	• A 5-Star GS Design & As Built v1.2 Rating	Aiming to achieve: • A 5-Star GS Design & As Built v1.1 Rating
Participants	Construction project manager, Client representative, Developer representative, Architect, Senior sustainability consultant, Construction project manager, Site engineer, Plastering contractor, Waste management contractor.	Developer representative, Masterplan architect, Sustainability consultant, End-user, Senior development manager, Quality assurance engineer, Senior design manager, Contracts administrator, Senior project engineer.	Client representative, Project procurement director, Construction project manager, Project design director, Quantity surveyor.	Construction project manager, Contract project manager, Project director of sustainability, environments and logistics, Project communication co-ordinator, Architect, Project building certifier.

Content analysis was the chosen method for interpreting the data from the PIs and CSs. This technique is effective for systematically analysing textual information to uncover significant patterns and themes, especially relevant to CE principles and WM strategies in construction [42]. The analysis, conducted using a deductive approach, was specifically structured to align with CE in the context of construction. The utilisation of NVivo software [43] facilitated a detailed and organised analysis, allowing for cross-case comparisons to identify both commonalities and differences, thus enhancing the study's overall insights [42,44].

4. Data Analysis

4.1. Circular Economy-Related Strategies to Manage Construction and Demolition Waste Identified from Preliminary Interviews

According to the interview findings, the process-related strategies to achieve CE-based C&D WM can be divided into five different categories, namely: "pre-design-related strategies", "design-related strategies", "construction-related strategies", "operation-related", and "end-of-life-related strategies", as shown in Table 3.

Table 3. Circular economy-related C&D WM strategies.

Category	Theme	Subtheme
Pre-design-related strategies	Early intervention conversations with key stakeholders to avoid C&D waste generation (5)	Early intervention conversations on the necessity of building new buildings to avoid C&D waste generation
		Early intervention conversations on the necessity of demolishing existing buildings to avoid C&D waste generation
Design-related strategies	Building design strategies to forecast and avoid C&D waste generation (16)	Designing for adaptation, longevity, deconstruction, resilience, disassembly, modularity, redundancy, dematerialization
		Designing for 'building in layers'
	Building materials or components selection to avoid C&D waste generation (8)	Choosing building materials with known origin and traced material flows
		Choosing recyclable and simple building materials/components that are suitable for recycling
		Choosing building materials without creating extra waste and transportation issues
		Providing building components as a service
Construction-related strategies	Building construction methods to avoid possible C&D waste generation (6)	Industrialising the construction process
		Undoing bonds without wasting materials
		Digitalising the construction process
	Effective onsite C&D WM (10)	Onsite building materials management development
		Ensuring appropriate C&D waste (source) separation and sorting facilities at construction sites
		Managing space and other facilities/resources available for CE-based WM
		Onsite intervention conversations with practitioners about implementing CE-based C&D WM
Operation-related strategies	Building maintenance approaches selection to prolong the life span of building materials/components (1)	Maintaining and repairing building components/elements
End-of-life-related strategies	Digital cataloguing systems development to enable a transparent closed-loop supply chain of building materials and components (5)	Building up waste material stock information to bring reusable/recyclable C&D waste materials/components/products to second-hand material markets
		Extending BIM application to the end-of-life use of a building

Notes: Numbers at the end of each statement indicate the number of participants who agreed on that particular point.

4.1.1. Pre-Design-Related Strategies

Improving C&D WM can be persuasively achieved if CE-based considerations are applied in the earlier stages of CPs, as shown in Table 3. It was identified that the earlier the project brief is challenged by implementing CE-based C&D WM, the better the effect on forecasting and minimising C&D waste generation in construction projects. Five interviewees mentioned that early intervention conversations with clients, developers, and architects about challenging project briefs could minimise C&D waste generation. It is possible to "*. . . plan or to encourage the developers, the clients, the architects, to minimise the amount of the waste they are going to generate in any project*" (Participant 3).

It was found that it is necessary to have early intervention conversations to reassess the necessity of developing new buildings or demolishing existing buildings to build new buildings and to consider the long-term impact on C&D waste generation. Some participants also highlighted that reducing the demand for, and building fewer, unnecessary new buildings can significantly avoid C&D waste generation. To avoid C&D waste generated by demolishing existing buildings, it is always good to "*. . . encourage the developers to include those existing buildings in the new developments* . . ." (Participant 3), and also always good to explore with clients from a strategic viewpoint alongside design teams whether to utilise existing buildings and avoid building new buildings (Participant 5). Also, it is important to design the buildings to be disassembled and reused as the use of buildings changes over time.

4.1.2. Design-Related Strategies

As mentioned above, the earlier stages are the most important for considering CE in C&D WM. Thus, the design stage is also crucial to make a more significant impact when applying CE. This stage has the largest potential to design as much C&D waste out of building projects as possible. As mentioned by interviewees, the appropriate selection of building design strategies can enable buildings and the materials/components they use to have a second life. Furthermore, it was identified that the digitalisation of the design process can support the prediction and avoidance of C&D waste flows easily, such as through effective BIM application. Then, understanding possible C&D waste flows by applying related waste-reducing strategies could reduce C&D waste effectively. In addition, participants indicated that designing for adaptation, longevity, resilience, redundancy, disassembly, dematerialisation, deconstruction, and modularity supported the avoidance of C&D waste generation, for example.

Alternatively, designing solutions for resilience is essential to minimise C&D waste (Participant 17). Theoretically, considering the secondary reuse of buildings and all their used materials/components at the design stage, it is easier to maintain as much residual performance of C&D waste materials as possible. However, among many CE strategies, only those that encourage construction technologies of assembling and disassembling with simple materials that do not consist of too many components that prevent reuse are applicable to increase the circularity potential of buildings in the CI (Participant 17). Thus, when looking at the design stage, designing for redundancy can be the first optimising tier for minimising C&D waste by considering all possible redundant building features used in the operation stage (Participant 6). At the initial design stage, another crucial consideration should be designing for disassembly.

Designing for deconstruction can also recover building resources at the end of a building's life (Participants 14 and 17), as can designing for modularity from the onset (Participant 19). Designing for 'building in layers': from a systematic perspective to look at the building life cycle,

> *. . . when you're talking about [the] circular economy [CE] . . . construction is the sharing layers model . . . you basically look at . . . your building in terms of . . . shell, . . . structure, . . . space, services, site . . . [so] you [need to] design . . . your building around the timeframe that you think that elements [are] going to last . . .* (Participant 8)

So that efficient use of building materials and components can be achieved by considering the durability of each layer based on its own life cycle.

Regarding the second theme, the building material- or component-selection strategies can enable the avoidance of new C&D waste generation in the future. Participants indicated many selection strategies, for example choosing building materials with known origins and traced materials flow: using building materials with materials passports will be a key factor for a good result for minimising C&D waste (Participants 11 and 16). "... *What the material[s] passport would do is give you visibility of how the waste ... is generated ... all the materials where the whole life cycle of it and that'll help us to really understand the C&D ... output and how do we reuse and recycle and repurpose it*" (Participant 15). Choosing recyclable and simple building materials/components that are readily recycled, choosing building materials without creating extra waste and transportation issues, sourcing local materials (Participants 15 and 20), and providing building components as a service (renting building façades or leasing fittings and fixtures) can help to minimise C&D waste generation (Participants 5, 8, and 18).

4.1.3. Construction-Related Strategies

The construction stage is the stage to apply the above-mentioned design-related strategies. Thus, improvements in building construction methods to avoid possible C&D waste generation should be considered first: "... *A good project conceived with these concepts of rationalisation of the construction process ... will favour a result focused on the circularity of the construction, not least because little waste will be generated*" (Participant 11). Based on rationalising the construction process, "... *it's actually not very hard to set up a building without creating any waste on the site ... because of the enablement of the two fields, pre-manufacturing and bringing everything on site and using that ...*" (Participant 13), that is, industrialising the construction process—a combination of manufacturing and construction. Thus, it needs to look for suitable technology for modularisation or prefabrication in different buildings. For example, some participants mentioned that using mechanical bonds rather than chemical/nailed connections should be considered when modularising or prefabricating a building to ensure less wastage when undoing bonds at the end of the life of buildings (Participants 14 and 17). Meanwhile, according to Participant 13, digitalising the construction process needs to be applied to building construction to support industrialising.

Participants highlighted the importance of onsite C&D WM to minimise C&D waste effectively. Most importantly, onsite building-material management and development need to be considered to avoid wasting unused building materials/components, such as developing feasible and smooth building-material return processes (Participant 8) and building-material tracking systems (Participant 16). Appropriate C&D waste (source) separation and sorting facilities at construction sites need to be arranged, for example by providing enough material-separation bins and material-storage places (Participants 4 and 10). Managing space and other facilities/resources available for CE-based WM is also fundamental for effective onsite C&D WM (Participants 4 and 7). Meanwhile, onsite intervention conversations with practitioners about implementing CE-based C&D WM need to be conducted to guide stakeholders' behaviours (Participant 19), for example, properly separating C&D waste (source) at construction sites (Participants 4, 6, and 17) and adequately using C&D waste (source) at construction sites (Participants 7, 12, and 13).

4.1.4. Operation-Related and End-of-Life-Related Strategies

According to the participants, developing digital cataloguing systems can enable a transparent closed-loop supply chain of building materials and components, including building up waste material stock information to bring reusable/recyclable C&D waste materials/components/products to second-hand material markets, for example, as well as material banks, material databases, and material inventories (Participants 1, 5, 6, 16, and 17). This strategy can integrate with the construction-related strategy mentioned above, that is, "building materials tracking systems". Extending BIM application from the design stage to the end of a building's usable life (Participant 1). Meanwhile, an appropriate selection of building maintenance approaches can prolong the usable life of building materials/components, such as choosing to repair building components/elements (Participant 2).

4.2. Circular Economy-Related Construction and Demolition Waste-Management Strategies Identified from Case Studies

Figure 2 presents an overview of the various stages in which CE and related strategies are applied to minimise waste in four different case studies (A, B, C, and D). Each of the four case studies clearly adopts different waste-minimisation strategies within the CE context. These strategies are divided into five categories: pre-design, design, tendering and contract, construction, and operation stage-related strategies.

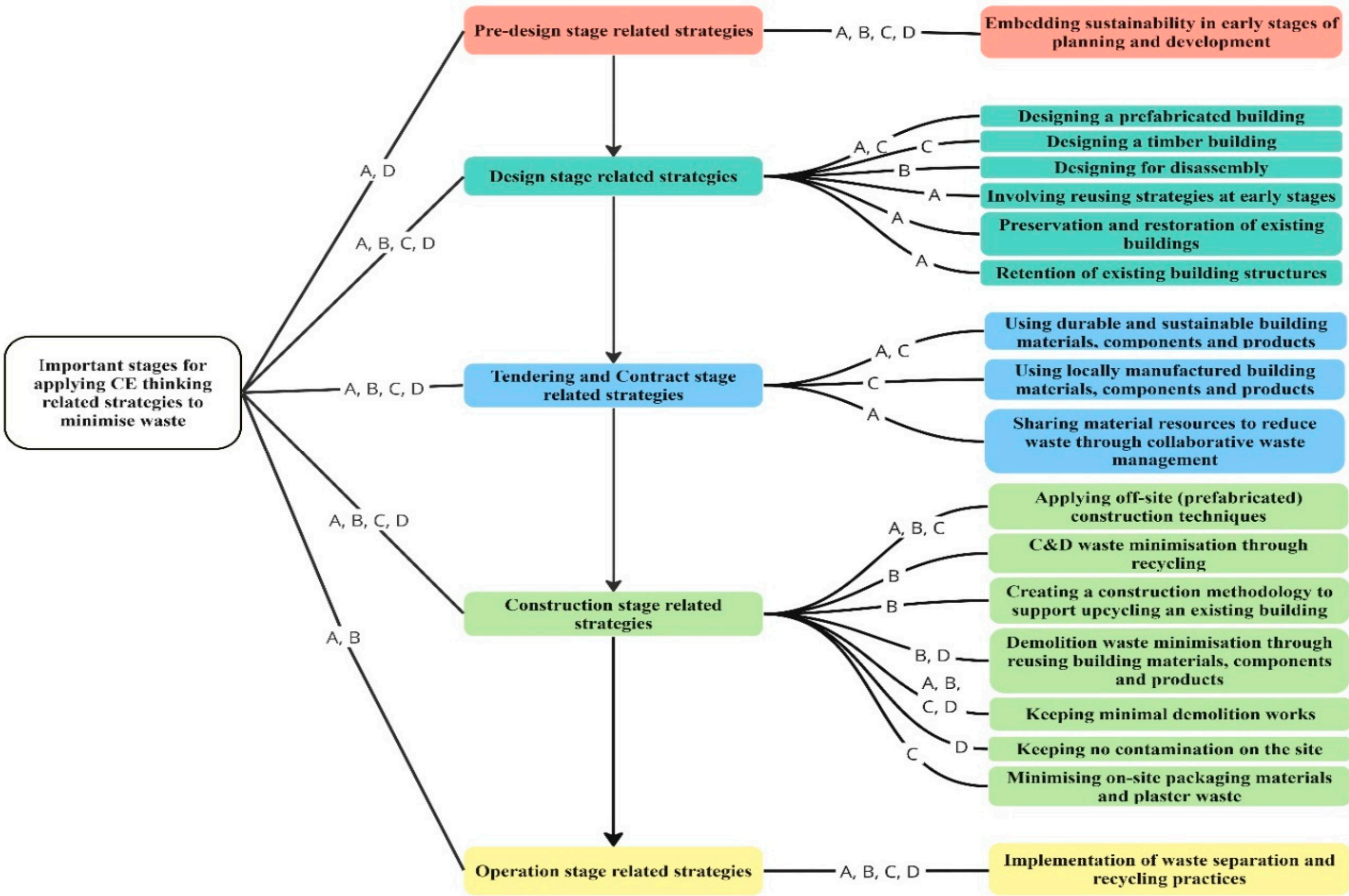


Figure 2. Circular economy-based waste-minimisation strategies applied in four case studies. Note: A = Case study A; B = Case study B; C = Case study C; D = Case study D.

4.2.1. Pre-Design Stage-Related Strategies

The pre-design stage theme emphasises the importance of early stakeholder engagement, sustainability considerations, and establishing priorities in the initial phases of a project. The findings of case studies have highlighted the importance of embedding sustainability in the early stages of planning and development of construction projects. By incorporating sustainability measures like solar panels and water-harvesting systems early in the project, stakeholders can ensure that these considerations are integral to the project's development and contribute to more sustainable outcomes. Project Director of Sustainability, Environments and Logistics D further emphasised that "... *we need to include sustainability in the very earliest conceptual thinking, right from the very start when it's just a thought bubble* ...". This statement underlines the importance of embedding sustainability and CE principles in project briefs, concept planning, and early stages of thinking to ensure that these concepts are not only acknowledged but actively integrated throughout the project.

Site Engineer A offered a complementary perspective, highlighting the importance of considering sustainability before the project reaches the construction team. This perspective reinforces the need for early engagement and collaboration between stakeholders, consultants, and architects to ensure that sustainability and CE principles are integrated into the project from the outset. Notably, as a client representative, Project Development Director A mentioned that it is crucial to engage efficiently with sustainability and CE concepts in the planning and development stages. This statement highlights the importance of addressing sustainability and CE principles in the early stages of project planning and development, ensuring a solid foundation for these concepts throughout the project's life cycle.

4.2.2. Tendering and Contract Stage-Related Strategies

The tendering and contract stage-related strategies are crucial for waste minimisation strategies in CPs. Various themes have emerged from case studies, such as using long-lasting and eco-friendly building materials, obtaining locally manufactured materials, and sharing resources to reduce waste through collaborative WM.

Incorporating durable and environmentally friendly building materials, components, and products is a critical aspect of an effective procurement strategy. As noted by Sustainability Consultant A, the emphasis is on employing "*recycled timber and the use of recycled materials*" and integrating "… *concrete with supplementary cementitious material[s] replacement instead of cement*". Site Engineer A also underscored the significance of including "*recycled material[s] content, particularly in concrete*". Using sustainable materials, such as cross-laminated timber (CLT), can significantly diminish waste and carbon footprints, as highlighted by Project Director C.

Another emerging theme identified is the significance of utilising locally manufactured building materials, components, and products. Project Director C shared their experience of procuring façade and furniture components from local manufacturers, aiming to minimise pollution and support local employment. Project Procurement Director C also mentioned implementing policies to engage local resources as much as feasibly possible. These practices can contribute to the sustainability of the construction project and the local community.

The final theme that came to light is sharing resources to reduce waste through collaborative WM. Plastering Contractor A emphasised the advantages of collaborating with other trades on the same job in the CI by ordering materials from the same company and reusing packaging materials such as pallets, stating that

> *[w]e've got a type of material, which is the other trades on the same job … are using. We're buying material together, which means we're sharing a similar material or the same material. So, it's being chopped off both sides, the wastage. So sometimes, I can use their offcuts, or sometimes they can use our offcuts.*

This co-operative approach can minimise waste and improve the construction project's sustainability.

4.2.3. Design Stage-Related Strategies

Design stage-related waste minimisation strategies can be categorised under several themes, including designing a prefabricated building, designing a timber building, designing for disassembly, involving reuse strategies at early stages, preserving and restoring existing buildings, and retaining existing building structures. Designing a prefabricated building has been shown to be a significant consideration in waste reduction on construction sites. According to Construction Project Manager C from the builder's side, prefabrication drastically limits onsite waste, particularly when it comes to concrete and plasterwork. This approach highlights the importance of considering prefabrication during the design stage to optimise waste minimisation.

Another design strategy that contributes to better environmental outcomes is the use of timber in building design. Quantity Surveyor C explained that timber buildings offer distinct advantages compared to traditional concrete and steel constructions, primarily due to their lower carbon emissions. This underscores the potential benefits of incorporating timber as a primary construction material in design strategies. Designing for disassembly is an approach that facilitates the reclaiming or salvaging of building components at the end of their life. Sustainability Consultant B elaborated that, by designing a façade as a curtain-wall system, many components associated with the curtain wall and façade can be taken apart and reclaimed. This design strategy emphasises the importance of considering a building's end-of-life phase during the initial design process.

Involving reuse strategies at early stages has become a more common consideration in the CI. Architect A pointed out that reusing materials, such as scaffolding and formwork, is increasingly being taken into account early in the project life cycle. This demonstrates the need for a shift in industry practices towards early incorporation of waste reduction strategies in the design process. Furthermore, preservation and restoration of existing buildings are other strategies that can help minimise waste. Developer Representative B described how retaining and upgrading existing buildings contributes to waste reduction in their project. This highlights the potential benefits of considering the adaptive reuse of existing structures in design strategies.

Retention of existing building structures has also been shown to have significant waste-reduction benefits. Senior Project Engineer B explained that the decision to retain the existing structure of a project has a considerable impact on minimising demolition waste. This emphasises the importance of evaluating the potential for retaining existing structures during the design process to achieve waste-minimisation goals. In order to implement these strategies effectively, it is essential for architects, engineers, and other stakeholders in the CI to collaborate and integrate waste-minimisation considerations from the early stages of design. By adopting a proactive approach and prioritising sustainable practices in the design process, the CI can work towards reducing its environmental footprint and contribute to a more sustainable future.

4.2.4. Construction Stage-Related Strategies

The application of off-site (prefabricated) construction techniques is a prominent waste-minimisation strategy in some of the case studies. In one instance, Sustainability Consultant A highlighted the prefabrication of materials such as cross-layers, timber beams, and slabs in a factory setting, which is different from traditional construction methods. Architect A supported this notion, stating that the building is modularised and prefabricated, with timber construction elements, prefabricated columns, and beams and façades manufactured off-site, significantly reducing waste associated with onsite fabrication. This approach to off-site prefabrication is further emphasised by a construction project manager, commenting on the benefits of factory settings with more control over goods, leading to less waste on site (Construction Project Manager C from the builder's side).

Another notable waste-minimisation strategy involves minimising C&D waste through recycling. Sustainability Consultant B discussed the onsite recycling methodology, where different colour-coded bins facilitate the recycling of up to 90% of construction waste. In addition, Senior Design Manager B explained the efforts to recycle as much material as possible during demolition, including stone cladding, furniture, and cables. Creating a construction methodology to support up-cycling an existing building is also an important waste-minimisation strategy. Masterplan Architect B mentioned the development of a construction methodology that allows the new structure to settle just enough to integrate with the existing structure. Demolition waste minimisation through the reuse of building materials, components, and products is another significant strategy. Client-side Construction Project Manager D emphasised the encouragement and use of materials and product reuse in their projects. Additionally, Developer Representative B described the reuse of travertine, a green stone, from the lobby of an existing building in the outdoor pedestrian areas of the project. Lastly, minimising onsite packaging materials and plaster waste is an essential aspect of waste minimisation. As a client representative, Project Director C explained that traditional construction methods generate significant waste from offcuts and packaging materials, whereas focusing on reducing such waste can contribute to sustainable construction practices.

Keeping demolition works to a minimum is another approach employed in waste-minimisation strategies. Client-side Construction Project Manager D explained that minimal demolition was involved in their project, as the site was mostly empty. Similarly, Senior Project Engineer B emphasised that their strategy revolved around retaining the existing structure rather than minimising demolition waste. Maintaining a contamination-free site is also crucial in waste minimisation. Client-side Construction Project Manager D mentioned that their site had no contamination, allowing them to return excavated soil to the landfill.

4.2.5. Operation Stage-Related Strategies

Implementing waste separation and recycling practices during the operation stage is a crucial aspect of waste minimisation strategies in CPs.

As indicated in the interview transcriptions, Senior Project Engineer B highlighted the importance of sorting waste materials during the operation stage, contributing to more effective WM. Project Engineer B also stated that "*. . . from an operation point of view, there's probably a bit more sort in, like separating waste. I can see, when I was walking through the floors, that they could separate, like cardboard . . . waste, recyclable, etc. . . .*". As shown in Figure 3, the red-lid bins are for general waste, the yellow-lid bins are for mixed recycling waste, the green-lid bins are for organic waste, and the blue bins are for mixed paper and card.

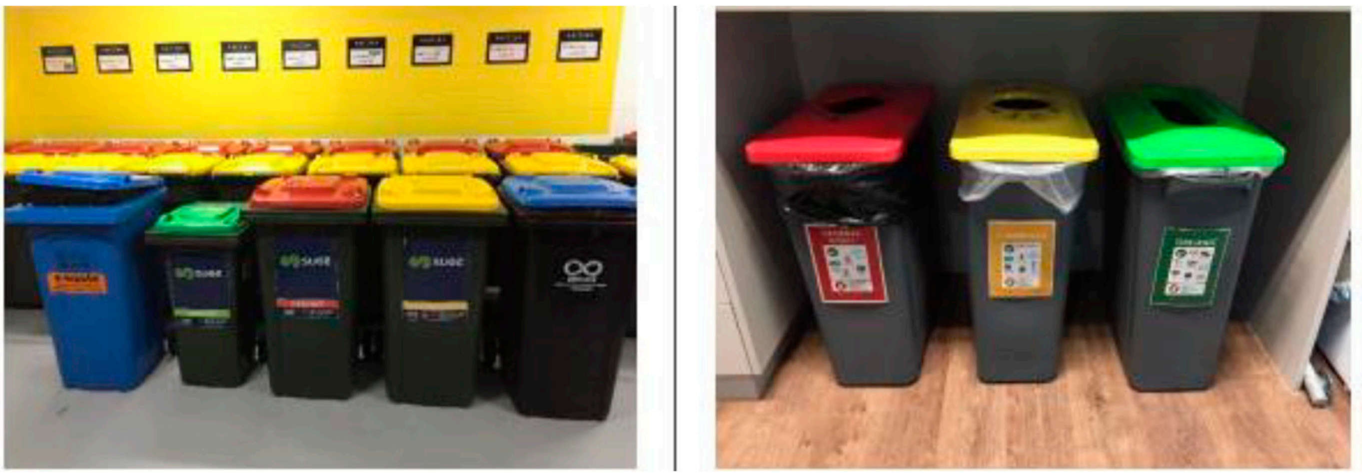


Figure 3. Bins and containers for waste separation in the operation stage in Case Study B. Source: retrieved from Project B's WM plan.

A similar waste separation approach is used in Case Study C, as shown in Figure 4. This approach to WM is essential as it helps streamline the waste-disposal process and ensures that various waste materials are directed to the appropriate disposal or recycling facilities.

Senior Project Engineer B suggested that the waste-separation practices employed in the building contribute to its overall sustainability and WM efficiency. They further mentioned, "*I think when that comes down to the waste room, I would think that that gets split up and makes it overall better in a way as well . . .*". As shown in Figure 5 and in Case Study B, the waste will be initially collected in bins located on each office floor.

Figure 4. Examples of signage for Case Study C. Source: retrieved from Project C's WM plan.

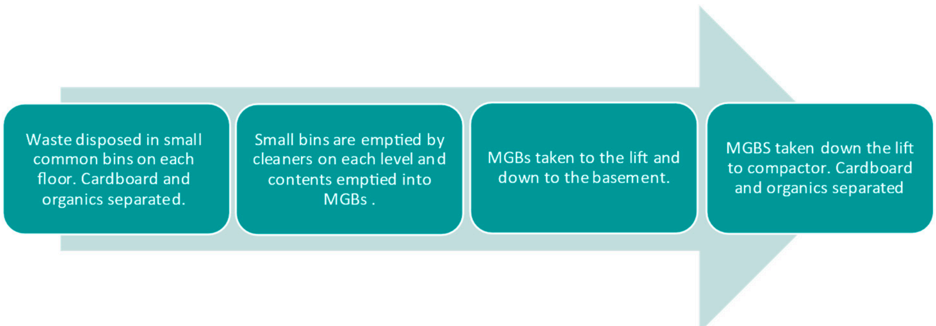
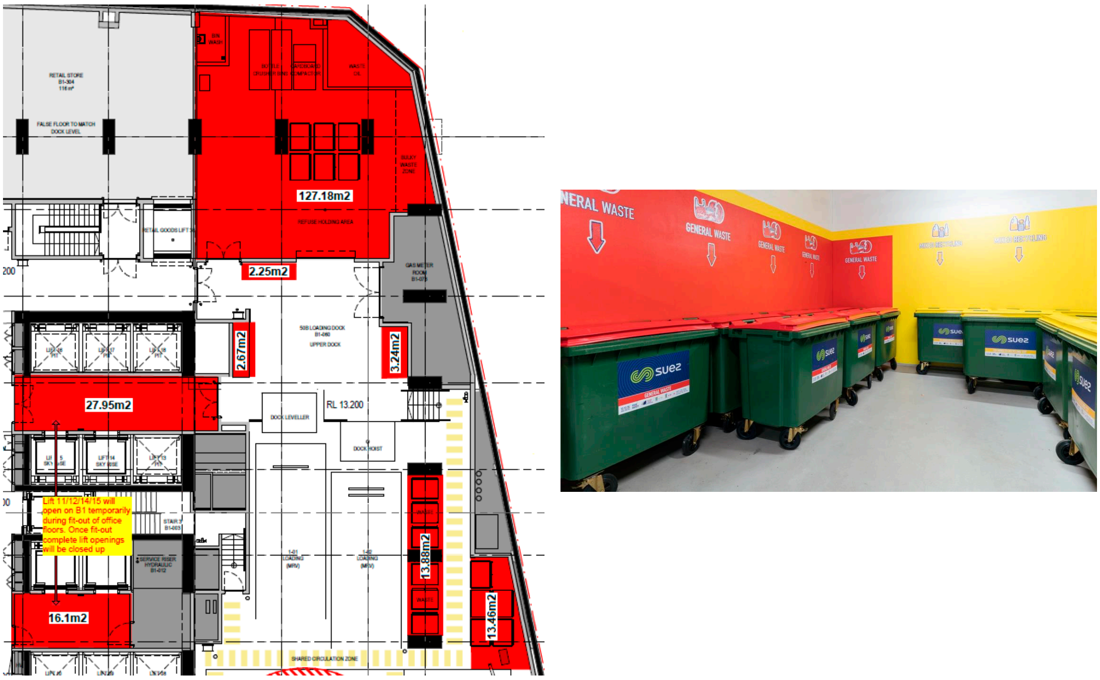


Figure 5. Waste-pathway flow summary in the operation stage for Case Study B. Source: retrieved from Project B's operational WM plan.

General waste and co-mingled recycling will be collected on each floor and will be taken in the related mobile garbage bins in the temporary loading dock via lifts to the basement in the Waste Storage Room, as shown in Figure 6.



(**a**) (**b**)

Figure 6. Waste storage room (**a**) and mobile garbage bins (**b**) used in Case Study B. Source: retrieved from Project B's operational WM plan.

Case Study D also involves a similar approach to storing and separating the collected waste from the building, as shown in Figure 7. This demonstrates that the operation stage of a construction project should not be overlooked when implementing waste-minimisation strategies. Integrating waste-separation and -recycling practices during the operation stage can significantly enhance a building's overall environmental performance.

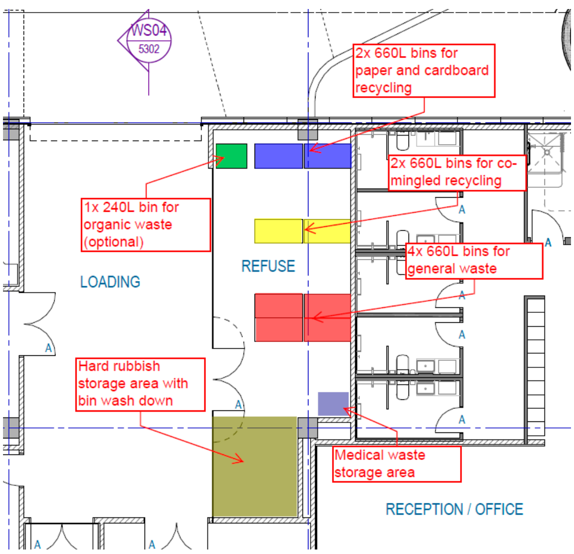


Figure 7. Indicative layout of the central waste storage room for Case Study D. Source: retrieved from Project D's operational WM plan.

5. Discussion of Circular Economy-Related Construction and Demolition Waste-Management Strategies in Construction Projects

Tables 4–9 illustrate CE-related C&D WM strategies across the literature review (LR), preliminary interview analysis (PIA), and case study analysis (CSA).

Table 4. Circular economy related C&D WM strategies in pre-design stages.

Category	Theme	Subtheme	Source
Pre-design-related strategies	Set sustainable goals and objectives	Set targets to minimise C&D waste	LR, PIA
		Promote resource efficiency	LR, PIA
		Reduce, reuse, and recycle materials	LR
	Early intervention conversations	Challenge the project briefs	LR, PIA
		Encourage decision-makers to minimise C&D waste generation	LR, PIA
		Discuss the necessity of constructing a new building or demolition of existing buildings by considering repurposing existing buildings	LR, PIA
	Stakeholder engagement	Fostering collaboration among clients, developers, architects, and contractors to make better decisions related to C&D WM	LR, PIA
		A shared understanding of WM goals	LR, PIA
	Whole-life-cycle considerations	Use LCA tools in evaluating environmental impacts and informing sustainable decision-making	LR

Table 5. Circular economy-related C&D WM strategies in design stages.

Category	Theme	Subtheme	Source
Design-related strategies	Building design strategies	Building Information Modelling	LR, PIA
		Designing for adaptation, longevity, resilience, redundancy, disassembly, dematerialisation, deconstruction, and modularity	LR, PIA, CSA
		Designing prefabricated buildings	CSA
		Designing timber buildings	CSA
		Involving reuse strategies at early stages	CSA
		Preservation and restoration of existing buildings	CSA
		Retention of existing building structures	CSA
	Building materials or components selection	Choosing building materials with known origin and traced materials flows	LR, PIA
		Choosing recyclable and simple building materials/components suitable for recycling	PIA, CSA
		Choosing building materials without creating extra waste and transportation issues	PIA, CSA
		Providing building components as a service	PIA

5.1. Pre-Design-Related Strategies

In Table 4, the findings emphasise the importance of implementing pre-design-related strategies in achieving effective C&D WM through CE application.

The findings of this research emphasise the importance of implementing pre-design-related strategies for achieving effective C&D WM through CE application. The literature underscores the need to establish sustainable goals and WM objectives, and to identify C&D WM strategies early.

Table 6. Circular economy-related C&D WM strategies in tendering and contract stages.

Category	Theme	Subtheme	Source
Tendering- and contract-related strategies	Specify WM requirements in tender and contract documents	Specify waste reduction targets	LR, CSA
		Specify recycling expectations	LR, CSA
		Request to submit WM plans	LR, CSA
		Set material-selection requirements by specifying the use of eco-friendly materials, recycled materials, and locally manufactured components	LR, CSA
		Request to submit an environmental management plan	CSA
	Assessing contractors' and suppliers' capacity and experience in minimising C&D waste	Consider completion of similar sustainable building projects as a prequalification criterion for selecting contractors and material suppliers	LR
	Supplier evaluation	Green procurement policies	CSA
	Incorporating sustainable WM practices in tender documents and contracts	Waste-reduction targets in tender documents	LR, CSA
		Recycling expectations in tender documents	LR, CSA
		WM plans in tender documents	LR, CSA
		Waste-management clauses in contracts	LR, CSA
	Collaborative WM to minimise C&D waste	Implied through shared resources and collaboration	LR, CSA
		Sharing materials and resources to reduce waste through collaborative WM	LR, CSA
	Performance incentives to encourage C&D WM targets to be exceeded	Specify financial rewards or penalties related to WM	CSA
		Contract extensions	CSA
		Preferential consideration for future projects	CSA

Table 7. Circular economy-related C&D WM strategies in construction stages.

Category	Theme	Subtheme	Source
Construction-related strategies	Rationalising the construction process	Industrialising the construction process	LR, PIA, CSA
		Undoing bonds without wasting materials	PIA
		Digitalising the construction process	PIA
	Effective onsite C&D WM	Onsite building-material management and development	PIA, CSA
		Ensuring appropriate C&D waste (source)-separation and -sorting facilities at construction sites	PIA, CSA
		Managing space and other facilities/resources available for CE-based WM	PIA, CSA
		Onsite intervention conversations with practitioners about implementing CE-based C&D WM	PIA
		Minimising onsite packaging materials and plaster waste	CSA
		Recycling C&D waste	CSA
		Reusing building materials, components and products	CSA
		Keeping demolition work to a minimum	CSA
		Maintaining contamination-free sites	CSA

Table 8. Circular economy related C&D WM strategies in operation stages.

Category	Theme	Subtheme	Source
Operation-related strategies	Building maintenance and retrofitting	Extend the building's life cycle Minimise C&D waste generation	LR, PIA, CSA LR, PIA, CSA
	Facility management practices	Sustainable material-use Resource-efficient processes	LR, CSA LR, CSA
	Waste-management plans	Handling, disposal and recycling of waste Generated from maintenance and retrofitting	LR, CSA LR, CSA
	Monitoring and reporting on WM performance	Identify opportunities for improvement Ensure compliance with WM targets	LR, CSA LR, CSA
	Building maintenance approaches	Maintaining and repairing building components Prolong the use-life of building materials	LR, PIA, CSA LR, PIA, CSA
	Waste-separation and -recycling practices	Streamline the waste-disposal process Direct waste materials to appropriate facilities Enhance overall environmental performance	LR, CSA LR, CSA LR, CSA

Table 9. Circular economy-related C&D WM strategies in end-of-life stages.

Category	Theme	Subtheme	Source
End-of-life stages	Deconstruction and material recovery	Selective demolition techniques	LR, PIA
		Proper planning and co-ordination	LR, PIA
		Digital cataloguing systems	PIA
		Building-material tracking systems	PIA
	Reverse logistics systems	Collection, transportation, and processing of waste	LR, PIA
		Partnerships with recycling facilities	LR, PIA
		Developing markets for recycled materials	LR, PIA
		Building up waste-material stock information	PIA
	Building Information Modelling	Extending BIM application to the end of life of a building	PIA

The literature and preliminary interview findings converge on the significance of early intervention and engagement with key stakeholders in the pre-design stage, highlighting the potential for waste reduction and resource efficiency. Furthermore, the preliminary interview findings reveal the importance of questioning whether constructing new buildings or demolishing existing ones is necessary. This perspective aligns with the waste-reduction principles of the CE, which advocate for maximising resource efficiency by reducing, reusing, and recycling materials [13]. From the PIA, by exploring alternative solutions such as repurposing existing buildings or avoiding unnecessary new constructions, significant C&D waste generation can be prevented. The PIA complements this view by stressing the need for early intervention conversations with clients, developers, and architects, as well as challenging project briefs to minimise C&D waste generation. These findings suggest that addressing C&D WM at the pre-design stage leads to more effective long-term WM throughout the project life cycle.

In addition to early intervention conversations, the LR also emphasises the importance of engaging key stakeholders in the pre-design stage, fostering collaboration and a shared understanding of WM goals [14]. The PIA supports this notion, suggesting that early discussions between architects and clients can yield design options considering C&D waste avoidance. This reinforces the idea that decisions made at the beginning of a project have the most significant impact on WM outcomes, while early engagement can facilitate more sustainable decision-making (PIA). Moreover, the literature highlights the importance of using LCA tools in evaluating environmental impacts and informing sustainable decision-making in construction projects [12]. Although the preliminary interview findings do not specifically mention LCA, the emphasis on considering the whole life cycle of a building during early intervention conversations (PIA) indicates a similar focus on understanding and addressing the long-term environmental implications of CPs.

5.2. Design-Related Strategies

Table 5 highlights the design-related strategies identified in this research.

As shown in Table 5, the LR highlights the importance of BIM in supporting WM strategies [18]. The PIA also supports the effective application of BIM in predicting and avoiding C&D waste flows. This finding is consistent with the CSA, which does not explicitly mention BIM but emphasises the importance of early-stage design strategies for waste minimisation, such as designing prefabricated buildings. Participants emphasised several design strategies, such as designing for adaptation, longevity, resilience, redundancy, disassembly, dematerialisation, deconstruction, and modularity (PIA). These strategies align with the findings from the LR, which recommends incorporating sustainable materials and systems [15,18,19]. Additionally, the CSA supports designing for disassembly as a crucial waste-minimisation strategy. Overall, consensus is found across the three sources on the significance of incorporating waste-reduction strategies during the design stage.

The PIA emphasises the importance of choosing building materials with known origin and traced materials flows, which aligns with the LR's recommendation of using sustainable materials such as green concrete and low-embodied energy materials [17]. The CSA also stresses the value of using timber as a primary construction material due to its lower carbon emissions. The PIA further highlights the importance of selecting recyclable and simple building materials, or components suitable for recycling. This finding is consistent with the CSA, which indicates that reusing materials such as scaffolding and formwork is increasingly being considered early in projects' life cycles. Additionally, the PIA and CSA both emphasise the significance of reducing transportation issues and waste generation by sourcing local materials. The CSA highlights the importance of preserving and restoring existing buildings and retaining existing building structures to minimise waste. These strategies were not explicitly mentioned in the LR and PIA. However, designing for adaptation and longevity, as mentioned in the PIA, could be interpreted as indirectly supporting the preservation, restoration, and retention of existing buildings.

5.3. Tendering- and Contract-Related Strategies

As shown in Table 6, both the LR and CSA emphasise the importance of incorporating WM requirements into tender documents and contracts.

The CSA specifically recommends including waste-reduction targets, recycling expectations, and WM plans in tender documents [22]. Furthermore, contracts should incorporate clauses related to C&D WM, such as waste-reduction and -recycling targets, WM-plan development and implementation, and regular waste monitoring and reporting [14]. These recommendations are consistent with the themes emerging from the LR, which also highlights the need to integrate waste minimisation strategies into the procurement process. Aligning these practices ensures that WM objectives are embedded in CPs from the outset, fostering a shared commitment among all stakeholders.

The LR highlights the importance of employing long-lasting and eco-friendly building materials, sourcing locally manufactured components, and sharing material resources to reduce waste through collaborative WM to enhance the environmental performance of CPs (CSA). An important premise to note is that contractors and suppliers who exhibit a strong track record, hold relevant environmental certifications, and propose effective WM strategies are more likely to contribute to a project's overall sustainability. During the tender-evaluation process, it is crucial to evaluate the ability and experience of contractors and suppliers in handling C&D waste. This assessment can be conducted by examining their past performance, the environmental certifications they hold, and the WM plans they propose [20].

On the other hand, the CSA emphasises the implementation of green procurement policies during the tendering stage to prioritise environmentally responsible contractors and suppliers [21]. Both approaches aim to minimise waste and promote sustainability in CPs, however, they target different aspects of the procurement process. The LR focuses on material selection, local sourcing, and resource-sharing practices, while the CSA highlights the importance of incorporating environmental requirements into the tender documents and evaluation process. Integrating these strategies can ensure a comprehensive procurement approach that addresses both material and supplier selection, leading to improved environmental performance in CPs.

The CSA suggests incorporating performance incentives into contracts to encourage contractors to exceed WM targets and foster a culture of continuous improvement [23]. These incentives may include financial rewards or penalties, contract extensions, or preferential consideration for future projects. While the LR does not explicitly discuss performance incentives, the theme of sharing materials and resources to reduce waste through collaborative WM (CSA) implies that stakeholders can be motivated to minimise waste and improve sustainability in CPs. Performance incentives can complement this co-operative approach by further encouraging contractors to adopt waste-reduction practices and promote a competitive edge in environmentally responsible construction.

5.4. Construction-Related Strategies

The construction-related strategies are discussed in Table 7.

As shown in Table 7, the LR highlights the importance of designing for deconstruction and using modular and prefabricated components to improve material recovery and reuse [16,35]. Similarly, the PIA emphasises the need to industrialise the construction process using suitable technologies such as modularisation or prefabrication. The CSA further supports this notion, with off-site (prefabricated) construction techniques being a prominent waste-minimisation strategy. Comparing these sources, it is evident that rationalising the construction process through modularisation and prefabrication is a widely accepted strategy for waste minimisation. By streamlining the construction process, it becomes easier to dismantle and reuse materials, contributing to a CE. Furthermore, the use of mechanical bonds, as mentioned by PIA, ensures minimal waste generation when undoing connections at the end of a building's life cycle.

All three sources emphasise the importance of effective onsite WM. The LR calls for waste sorting, segregation, and recycling to enhance resource efficiency and divert waste from landfills [25]. The PIA suggests developing feasible building-material return processes and building-material tracking systems. Additionally, providing adequate separation and sorting facilities at construction sites, and managing space and other resources for CE-based WM, are essential (PIA). In line with these findings, the case studies highlight the importance of recycling C&D waste through colour-coded bins and reusing building materials, components, and products. Furthermore, minimising onsite packaging materials and plaster waste is crucial for waste minimisation (CSA). Comparatively, it is clear that effective onsite C&D WM is a critical strategy for minimising waste generation. This includes proper waste sorting, and recycling and reusing materials, as well as efficient building-material management. By implementing these practices, CPs can significantly reduce waste and contribute to more sustainable and environmentally friendly practices.

The preliminary interviews highlighted the importance of onsite intervention conversations with practitioners to guide stakeholder behaviour towards implementing CE-based C&D WM. The case studies further emphasised the need for minimal demolition works and maintaining contamination-free sites. These findings indicate that stakeholder engagement and behaviour change are vital components of waste-minimisation strategies. By involving stakeholders in the WM process and promoting sustainable practices, CPs can better achieve their waste-reduction targets.

5.5. Operation-Related Strategies

During the operation stage of a building, several strategies can be employed to minimise C&D waste generation, as identified in the LR, PIA, and SCA, and shown in Table 8. These strategies include regular maintenance and retrofitting, implementation of facility management practices, development of WM plans, monitoring and reporting on WM performance [29], maintaining and repairing building components (PIA), and waste-separation and -recycling practices (CSA).

The importance of regular maintenance and retrofitting to extend the building's life cycle and reduce C&D waste generation [29] is echoed in the interview findings, where maintaining and repairing building components are identified as strategies to prolong the use of building materials and components (PIA). This is further exemplified in the CSA, where waste-separation and -recycling practices are implemented during the operation stage. All case studies demonstrate WM efficiency and contribute to the overall sustainability of the buildings.

The implementation of facility-management practices that prioritise the use of sustainable materials and resource-efficient processes [29] is evident in the case studies, particularly in the waste-separation and -recycling practices adopted. Waste-separation practices contribute to efficient WM by directing waste materials to appropriate disposal or recycling facilities (CSA). These practices align with the WM plans for the operational phase, as recommended in the literature. Monitoring and reporting on WM performance during the operation stage can help facility managers identify opportunities for continuous improvement [29]. Although not explicitly discussed in the case studies, the emphasis on waste-separation and -recycling practices implies that monitoring and reporting are part of the overall WM approach.

The comparisons among the LR, PIA, and CSA highlight the importance of integrating waste-minimisation strategies throughout the building's life cycle, including in the operation stage. By adopting maintenance and retrofitting strategies, implementing facility management practices, developing WM plans, and incorporating waste-separation and -recycling practices, CPs can contribute to the long-term sustainability of the built environment and promote responsible WM practices. However, it is essential to acknowledge that implementing these strategies may vary across projects due to differences in building types, locations, and stakeholder involvement. To ensure the successful implementation of operation stage-related strategies, stakeholders must collaborate and maintain open communication channels.

5.6. End-of-Life-Related Strategies

The end-of-life-related strategies are highlighted in Table 9.

The LR emphasised the importance of deconstruction, material recovery, and recycling as key strategies at the end-of-life stage [29,30]. Selective demolition techniques prioritising the separation and sorting of materials can facilitate recycling, contributing to the CE. Proper planning and co-ordination during the deconstruction process can maximise the recovery rate and minimise waste generation. Similarly, the participants highlighted the need for a transparent closed-loop supply chain of building materials and components facilitated through digital cataloguing systems (PIA). This strategy aligns with the construction-related strategy of building-material tracking systems mentioned in the interviews.

The LR also underlined the significance of employing reverse logistics systems in C&D WM [29]. Reverse logistics systems involve the collection, transportation, and processing of waste materials from deconstruction sites to recycling facilities, ensuring effective material-recovery and -reintegration into the production cycle. Furthermore, the LR emphasised the importance of establishing partnerships with local recycling facilities and developing markets for recycled materials to promote resource efficiency and waste diversion from landfills [38]. In the interviews, the participants similarly noted the need to build up stock information on waste materials, which can bring reusable/recyclable C&D waste materials, components, and products to second-hand materials markets.

While not explicitly mentioned in the LR, the interviews revealed the potential benefits of extending BIM application from the design stage to the end life of a building. Incorporating BIM at the end-of-life stage can enable better tracking of materials and component inventories, thereby facilitating more efficient deconstruction, and material-recovery and -recycling processes. This strategy complements the aforementioned strategies found in both the LR and the interviews, offering a holistic and integrated approach to managing real end-of-life stages.

6. Conclusions

This paper explored CE-related strategies for managing CDW. The key findings indicate the need for integrating CE at all stages of CPs to manage C&D waste. In the pre-design phase, it is paramount to set sustainable goals for construction projects to manage C&D waste, such as designing for deconstruction, using environmentally friendly materials, and planning for waste minimisation. These goals have a measurable impact on reducing the final amount of waste generated. For instance, designing for deconstruction facilitates easier material recovery and reuse, significantly decreasing waste sent to landfills. Furthermore, engaging stakeholders early ensures alignment of objectives towards waste minimization, and embedding WM considerations into contracts demonstrates a commitment to sustainability from project inception. The design phase offers substantial opportunities for waste reduction, particularly through BIM and designing for disassembly. For example, implementing design strategies such as modular design and the use of prefabricated components can significantly reduce waste. The construction phase benefits from using modular and prefabricated components, which streamline the building process and facilitate the reuse and recycling of materials. Prefabricated construction techniques can also minimise waste generation and energy consumption. In the operational phase, strategies such as regular maintenance and retrofitting extend the life of building materials, thus reducing waste generation. This also includes regular audits and the use of digital tools for tracking and managing waste. The end-of-life phase is crucial for employing selective demolition practices, as digital cataloguing is for material recovery and recycling. This can significantly reduce waste, enhance energy efficiency, and lower emissions.

Implementing CE-related C&D WM strategies across all stages of construction projects can lead to practical benefits, including moderate reductions in C&D waste generation, enhanced resource efficiency, improved stakeholder collaboration, and sustainable decision-making. These strategies can contribute to the long-term sustainability of construction projects, aligning with CE and promoting environmentally responsible construction practices. The paper also underscores the pivotal role of policy, technology, and stakeholder collaboration in advancing CE practices in construction projects to minimise C&D waste generation. Effective regulatory frameworks, investments in innovative technologies, and collaborative efforts among policymakers, industry practitioners, and researchers are vital for integrating CE to manage C&D waste across the construction project lifecycle. Further research should delve into the practical challenges of implementing these strategies and explore innovative technologies and methods for enhancing CE practices in construction. The transition to a more sustainable CI is not just beneficial but essential for environmental conservation and economic sustainability.

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