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REVIEW

Enhancing circularity in concrete waste management: a conceptual framework of stakeholder engagement, barriers and strategies for sustainable collaboration

Margaret Damilola Oyewole[1] · Daniel W.M. Chan[1] · Donald C. Nwonu[2,3] · Oyewole Clement Oyesomo[1]

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Abstract

Concrete waste accounts for the largest share of global construction and demolition waste, intensifying resource depletion, landfill pressure, and embodied carbon emissions from cement production. The circular economy offers a regenerative pathway through reduction/prevention, reuse, maintenance/repair/refurbishment, and recycling, yet implementation remains limited by socio-organisational challenges. While existing literature has advanced technical aspects of these strategies, stakeholder roles and collaboration in concrete-specific contexts remain fragmented and are often examined within broader construction and demolition waste frameworks. To address this gap, this study conducts a systematic review of 51 studies to examine stakeholder engagement, barriers and strategies in circular concrete waste management (CCWM). Eleven stakeholder groups were identified, and a Responsible-Accountable-Consulted-Informed (RACI) governance framework was applied to map stakeholder roles from design through end-of-life. The findings show that CCWM implementation depends on coordinated life-cycle engagement between primary value chain actors and supporting actors, with persistent gaps in accountability, early contractor involvement, traceability and sustainability performance assessment. The findings further revealed that unclear roles, undervalued expertise, misaligned priorities, regulatory inconsistencies, poor communication and limited knowledge sharing are cross-cutting barriers to collaboration. These barriers are relational than uniform, affecting stakeholders differently and requiring targeted interventions from actors with appropriate leverage. Effective collaboration, therefore, requires integrated mechanisms for capacity building, governance, economic incentives, digital support, and performance monitoring. The study integrates these insights into a socio-technical conceptual framework that links stakeholders, engagement barriers, and pragmatic strategies. This framework supports the diagnosis of coordination failures and prioritization of interventions to strengthen stakeholder collaboration and accelerate circular transitions in the construction sector.

Keywords Circular economy · Concrete waste management · Stakeholder roles · Collaboration · Challenges · Construction industry

Introduction

The construction sector is one of the largest consumers of natural resources and a significant generator of solid waste globally, accounting for an estimated 30–40% of total waste streams and substantial greenhouse gas emissions [1]. Among the materials used in this sector, concrete is the most prevalent but also one of the most environmentally taxing, responsible for nearly 9% of global CO_2 emissions and 3% of global energy demand due to cement production and the extensive extraction of raw materials [2, 3]. Globally, concrete production has nearly quadrupled since 1990

✉ Margaret Damilola Oyewole
margaret.oyewole@connect.polyu.hk

1 Department of Construction Management and Intelligence, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong

2 School of Civil Engineering, University of Leeds, Leeds LS2 9JT, UK

3 Department of Architecture and Civil Engineering, University of Bath, Claverton Down BA2 7AY, UK

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to 26 billion tons per year by 2020, driving virgin aggregate use to 20 billion tons per year, surpassing total fossil fuel extraction by mass and intensifying sand scarcity, along with related ecological and social impacts [4].

The end-of-life phase of buildings exacerbates this challenge, as concrete waste accounts for up to 50% of total construction and demolition (C&D) waste worldwide [1]. Projections by Chen, Li [5] indicate that global urbanization will accelerate through the 2040s and, under high-growth scenarios such as Shared Socioeconomic Pathway 5 (SSP5), continue to expand through 2100. As urban expansion directly increases demand for buildings and infrastructure, this long-term trajectory implies sustained growth in concrete consumption over the next 50–100 years [6]. These pressures highlight the urgency of implementing circular strategies that minimize resource loss and mitigate the environmental impacts of concrete production and disposal.

The circular economy (CE) has emerged as a transformative framework to address these challenges by promoting restorative and regenerative material flows that extend asset lifespan, minimize waste, and recover value at end-of-use [7, 8]. Applied to concrete, CE strategies encompass reducing material use through optimised design, producing durable, maintainable concrete, direct reuse, repair/refurbishment of elements, and high-value recycling to close material loops [9, 10]. These approaches offer substantial potential to lower embodied carbon, conserve natural aggregates, and support global zero-waste ambitions aligned with the Sustainable Development Goals (SDGs), particularly SDG 12 on responsible consumption and production [11].

Recent research has advanced technical innovations across individual strategies, including material reduction [12, 13], concrete recycling and recycled aggregate applications [14, 15], direct element reuse [16, 17], and eco-efficient repair and rehabilitation systems [18–20]. However, achieving systemic circularity extends beyond technology: it requires active, coordinated engagement of diverse stakeholders throughout the concrete lifecycle [21]. Emerging interdisciplinary research also highlights that the transition towards a CE is not solely a technical endeavour, but a complex socio-technical and governance process involving organizational change, coordination across value chains, and among heterogeneous actors [22]. Studies on CE transitions and sustainability-oriented innovation emphasize the importance of organisational orientation, leadership, and governance structures in enabling systemic circular transitions [23–25]. Similarly, evidence from waste recovery firms demonstrates that implementing sustainable practices depends not only on technological capability but also on the presence of integrative governance structures and social performance dimensions [26]. These insights suggest that material-specific circular strategies must be supported by robust stakeholder engagement and governance to achieve scalable, lasting impact.

Within CCWM, these dynamics are particularly important because clients, designers, contractors, manufacturers, demolition specialists, policymakers, and end-users each hold distinct influence, shaping project specifications, enabling design for disassembly, facilitating reuse logistics, or providing regulatory and economic incentives, yet collaboration across these actors remains constrained by fragmented responsibilities, misaligned incentives, and limited communication [27, 28].

Despite the growing body of literature, understanding stakeholder roles and collaboration challenges in concrete waste management (CWM) remains fragmented. Existing studies frequently examine these dimensions in isolation, focusing on stakeholder collaboration within individual strategies. For instance, stakeholders collaborating for reuse of concrete elements [29–31], stakeholders in concrete waste recycling and recycled product applications [32–34], or stakeholders in repair and rehabilitation of concrete structures [19], highlighting the need to connect them into a cohesive, lifecycle-spanning framework. Similarly, existing reviews, though informative, often address C&D waste broadly or focus predominantly on CE generally [35, 36]. As a result, the stakeholder interdependencies and coordination challenges across the project life cycle in implementing material-specific circular strategies remain underexplored.

This paper, therefore, addresses this gap by synthesizing stakeholder roles across the project life cycle, identifying collaboration challenges and strategies for effective collaboration and engagement, and offering a holistic framework that advances both conceptual understanding and practical guidance for implementing circular concrete waste management (CCWM). By focusing explicitly on concrete, a material with unique physical, structural, and durability characteristics, this review offers a novel socio-technical perspective that bridges technical circular strategies with the human and organizational factors essential for material circularity.

Through a systematic review of empirical and conceptual literature, the paper achieves four primary contributions:

1. It maps the specific roles and responsibilities of key stakeholder groups across the concrete lifecycle in implementing CCWM strategies using a RACI-based governance framework.
2. It identifies and synthesizes the barriers to effective stakeholder engagement in CCWM and links each barrier to both affected stakeholders and those who influence them.
3. It determines the pragmatic strategies for effective stakeholder engagement and collaboration in CCWM.

4. It proposes an integrated conceptual framework for stakeholders' engagement, barriers, and strategies for sustainable collaboration toward achieving circularity in the CWM transition.

The remainder of this paper is structured as follows. Section 2 presents the theoretical background; Sect. 3 describes the research methodology; Sect. 4 presents the results and discusses the findings; Sect. 5 integrates the findings into a conceptual framework; and Sect. 6 concludes the paper and outlines the study's limitations and future research directions.

Theoretical background

This section presents the theoretical foundation for the study, presenting the key concepts relevant to CCWM, including CE principles, CCWM strategies and stakeholder theory. CE principles explain the broader logic of keeping materials in use for longer, while CCWM translates these principles into concrete circular strategies, such as reduction, reuse, repair/refurbishment, and recycling. Stakeholder theory explains why the implementation of these strategies depends on the roles, interactions and collaboration of multiple actors across the project life cycle. Together, these concepts establish the basis for analysing how stakeholder engagement and collaboration shape the implementation of circular practices in CWM.

Circular economy (CE) and the built environment

The CE concept has attracted considerable attention from academia, governments, and industry as a systemic response to escalating environmental challenges and climate change. It presents a restorative and regenerative alternative to the traditional linear economy, which follows a "take-make-dispose" model [37]. Global commitment to CE is exemplified by initiatives such as the European Commission's action plans, China's Circular Economy Promotion Law, national CE packages in countries such as the United Kingdom, the Netherlands, and Norway, and a surge in scholarly publications [38].

In the built environment, CE principles involve designing buildings and infrastructure to minimize raw material extraction, prolong service life, and maintain materials in high-value use across multiple cycles [39]. As articulated by Kirchherr, Reike [40], CE constitutes an economic system that eliminates the "end-of-life" concept by prioritizing reduction, reuse, recycling, and recovery throughout production, distribution, and consumption processes. Operating at micro (products, companies, consumers), meso (eco-industrial parks), and macro (cities, regions, nations) levels, it seeks sustainable development by delivering environmental quality, economic prosperity, and social equity for present and future generations.

Core CE implementation rests on the foundational 3R principles Reduce, Reuse, and Recycle while evolving into expanded frameworks. Reduce focuses on minimizing resource inputs, energy use, and waste at the source [41]. Reuse extends product and component lifecycles, curtailing demand for virgin materials. Recycling reprocesses waste into new resources, conserves materials, and mitigates impacts. Contemporary extensions encompass up to 9 or 10 Rs, incorporating Refuse, Rethink, Repair, Refurbish, Remanufacture, and Repurpose [38, 42].

Applying CE in construction demands a paradigm shift, encompassing technology innovation, business models, multi-stakeholder collaboration, and supportive policies [43]. While these principles provide a robust foundation for sustainability in the built environment, their effective application to high-volume waste streams, such as concrete, requires tailored strategies that prioritize hierarchical interventions. The following section examines these concrete-specific circular strategies in detail.

Circular concrete waste management (CCWM)

Concrete waste accounts for the largest share of global construction and demolition waste [43]. These waste streams exacerbate landfill pressures, intensify resource depletion, and lock in embodied carbon. As a result, CE thinking has increasingly shifted CWM away from end-of-pipe disposal toward lifecycle-oriented value retention [44]. Key CE strategies for concrete include reduction, repair and refurbishment, direct reuse of components, and recycling into aggregates [12, 43, 45, 46] as presented in Fig. 1.

Reduction represents the most upstream strategy in CCWM, aiming to prevent waste generation and environmental impacts by minimizing material use, avoiding overdesign, and optimizing processes across the project lifecycle [42, 47]. The greatest leverage often lies in early design choices, where optimized structural systems, modularization and standardization, and performance-based specifications significantly reduce material demand and construction waste [12, 48]. Design strategies such as adaptability and disassembly principles, durable design, as well as construction-stage measures such as prefabrication, lean practices, and strong quality control can enhance recovery and reduce rework, defects, and inefficient handling [49, 50].

Reuse is recognized as a higher-value loop than recycling because it retains both the form and function of components. In concrete, reuse involves salvaging elements, often precast

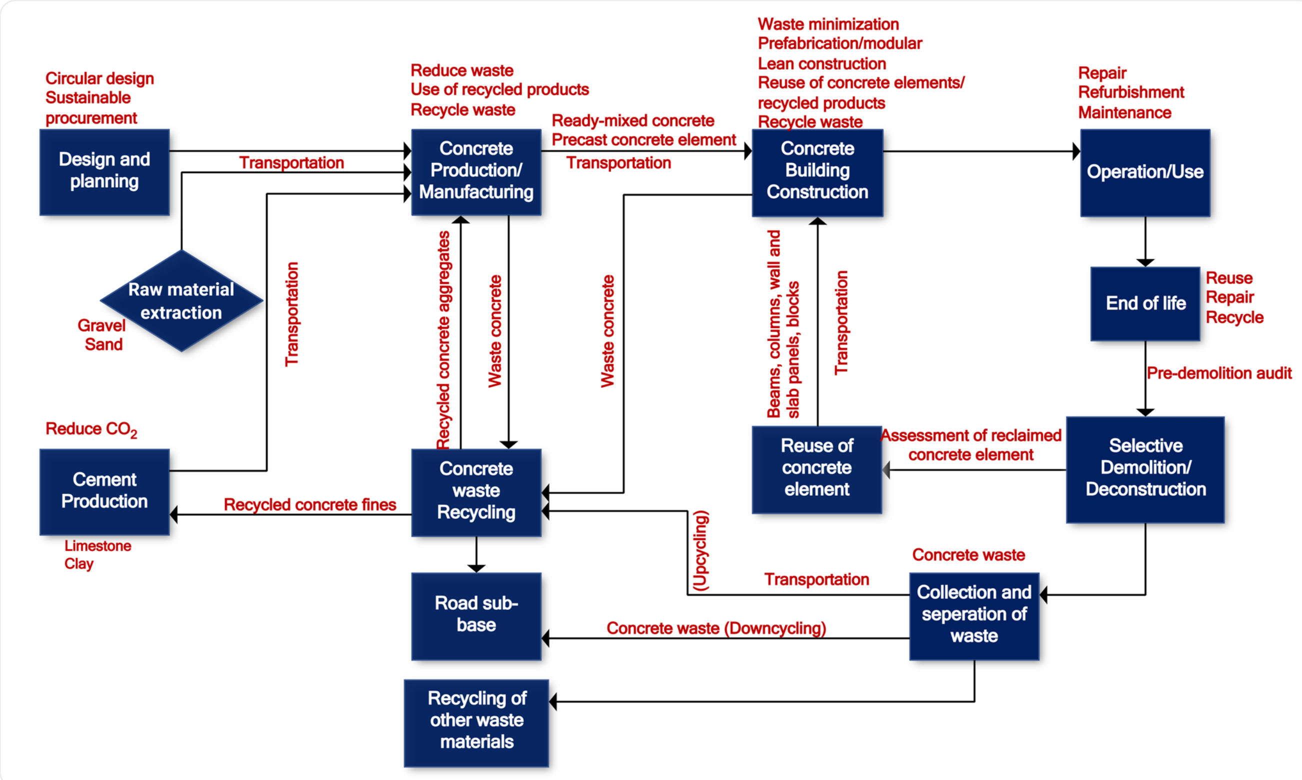

Fig. 1 A diagram illustrating CCWM strategies

panels, beams, slabs, or blocks and reintegrating them into new or refurbished projects, thereby avoiding energy-intensive reprocessing and reducing raw material extraction [51, 52]. However, reuse is highly dependent on early planning and enabling design decisions, including design for disassembly and reuse, standardization, reversible connections, and selective deconstruction that preserves the quality of recovered elements [53, 54].

Similarly, repair, refurbishment and maintenance strategies delay demolition and avoid waste generation while preserving embodied carbon in existing assets [42]. Maintenance typically involves inspection and preventive protection; repair addresses deterioration such as cracking, spalling, or reinforcement corrosion; and refurbishment encompasses broader strengthening or retrofitting while retaining the existing structural frame [19, 55]. Recent advancements in monitoring technologies, such as non-destructive testing, sensors, Internet of Things (IoT) and AI, together with eco-friendly materials such as high-performance and self-healing concrete, are expanding the feasibility of proactive and lower-impact interventions [18, 56, 57].

Another CE strategy is recycling, the most established and widely implemented approach. It involves the retrieval, sorting, and crushing of demolished concrete into recycled aggregates for applications such as road base, sub-base, and, increasingly, new concrete production [43]. While this approach diverts waste from landfills, the performance limitations of recycled concrete have constrained its use in structural applications. Recent advancements in selective demolition, automated sorting, and recycling technologies are significantly increasing the quality of recovered aggregates [58, 59]. Nevertheless, achieving circular outcomes is not only a technical issue: the feasibility of reduction, reuse, life extension, and high-value recycling depends on coordinated action across the value chain [33].

Stakeholder theory

Stakeholder theory, first conceptualized in the 1960s and prominently advanced in the 1980s [34, 60], offers a robust framework for analyzing sustainability transitions in the construction industry. The theory asserts that organizations function within interconnected networks of relationships, where the interests, resources, and actions of diverse stakeholders collectively influence outcomes [61].

A stakeholder is defined as "any group or individual who can affect or is affected by the achievement of the organization's objectives" [60], encompassing internal actors (e.g., project teams) to external entities (e.g., community, NGO), all of whom influence the advancement of sustainable practices [62, 63]. Stakeholder theory has been effectively applied in CE literature to drive sustainable transitions.

Rincón-Moreno, Ormazábal [64] showed that proactive stakeholder participation accelerates local CE transitions in Spain by fostering collaboration and innovation. Similarly, CE supply chain studies show that engaging forward, reverse, and external stakeholders enhances circularity across lifecycles [65]. Baah, Afum [66] further quantifies stakeholder influences on CE adoption, revealing that regulatory actors exert the strongest effect and that successful adoption enhances external stakeholder satisfaction and green legitimacy. Collectively, these studies highlight the critical role of stakeholder engagement in facilitating CE adoption across sectors and supply chains, thereby providing a compelling rationale for applying stakeholder theory to CCWM.

Within the context of CE and C&D waste management, stakeholder theory underscores that circularity cannot be achieved unilaterally, as waste prevention, material recovery, and lifecycle optimization require coordinated efforts across the building value chain [67]. The theory facilitates mapping of interactions and leverage points, enabling identification of decision touchpoints where interventions such as shared digital platforms, co-design processes, or collaborative procurement can amplify circular outcomes [68, 69].

However, because CCWM represents a circular transition involving systemic change across technologies, institutions, market, and project practices, the study also draws on complementary insights from network governance, institutional theory and socio-technical transition perspectives [70]. Network governance theory emphasises coordination, trust, shared responsibility, and information exchange among interdependent stakeholders in policy making and implementation [71], which is particularly relevant for understanding collaboration barriers and engagement strategies in CCWM. Institutional theory highlights how institutional environments, including laws, rules, and professional norms, shape stakeholder behaviour and influence sustainable transitions [72]. Socio-technical transition thinking further explains that circular construction transitions depend not only on technical innovation, but also on the alignment of institutions, market conditions, organisational practices, regulations, and stakeholder behaviours across the project life cycle [73]. Together, these perspectives provide a more nuanced understanding of how stakeholder interactions evolve and how systemic change can occur in circular construction systems.

In this study, stakeholder theory therefore serves as a lens within a broader socio-technical and governance context. It supports the integration of empirical and conceptual insights by enabling systematic mapping of stakeholder roles in CCWM, as well as the synthesis of engagement barriers, collaboration strategies and future research directions.

Table 1 Keyword search strings used in Scopus and Web of Science databases

Search Keywords	Number of Articles
(TITLE-ABS-KEY ("stakeholders" OR "consultants" OR "policymakers" OR "manufacturer" OR "professional" OR "contractor") AND TITLE-ABS-KEY ("roles" OR "responsibilities" OR "collaboration" OR "capabilities" OR "abilities" OR "engagement" OR "relationship" OR "barriers" OR "strategies") AND TITLE-ABS-KEY ("concrete waste" OR " waste concrete" OR "concrete demolition waste" OR "concrete building waste" OR "concrete waste management" OR "end-of-life concrete management" OR "construction and demolition waste management" OR "waste management") AND TITLE-ABS-KEY ("circular economy" OR " resource efficiency " OR " material circularity " OR "sustainability" OR "reuse" OR "reduce" OR "recycling" OR "recover" OR "close loop" OR "downcycling" OR "green economy" OR " cradle to cradle " OR " industrial ecology") AND TITLE-ABS-KEY ("construction" OR "construction industry" OR "construction sector" OR "AEC" OR "AECO" OR "building industry" OR "built environment"))	829

Research methodology

This study adopts an interpretivist research philosophy to explore and synthesize knowledge on stakeholder involvement in CCWM across the construction lifecycle. This approach enables in-depth engagement with existing literature, facilitating comprehensive synthesis and integrative insights [74]. A systematic literature review (SLR) was adopted as the primary research strategy due to its efficacy in identifying and synthesizing evidence from a dispersed body of secondary studies [75]. The review followed PRISMA guidelines to ensure transparency, reproducibility, and methodological rigour [76].

Literature sources and search strategy

A comprehensive literature search was conducted in September 2025 using the Scopus and Web of Science databases, selected for their extensive coverage of peer-reviewed research in construction management, sustainability, and CE. The search was applied to article titles, abstracts, and keywords (TITLE-ABS-KEY) and employed a combination of theme-based keywords and Boolean operators to capture stakeholder involvement, roles and capabilities, CWM, CE principles, and the construction industry context, as shown in Table 1.

Selection process of reviewed studies

The study selection process was guided by inclusion and exclusion criteria. The database search retrieved 829 records

(Scopus: 584; Web of Science: 245). All records were imported into a reference management software, where 32 duplicates were identified and removed, leaving 797 records for screening. Title and abstract screening were then undertaken to exclude publications that were non-English, lacked identifiable authorship, or did not address stakeholder roles, engagement, collaboration challenges, or strategies in construction waste management. This stage resulted in the exclusion of 682 records, and 115 records were subjected to full-text screening. Full texts were assessed for eligibility based on relevance to concrete waste management, explicit consideration of stakeholder involvement, and availability of the complete article. This assessment led to the exclusion of 64 articles. In total, 51 records met all eligibility criteria and were included in the review.

While the PRISMA-guided systematic process strengthened transparency and replicability, potential selection biases within the evidence base are acknowledged. First, the restriction to English-language publications indexed in Scopus and Web of Science may have excluded relevant studies from regional databases, non-English sources, industry reports, and policy documents. In addition, the final evidence base reflects uneven geographical concentration, with a stronger concentration of studies from China, Europe and Australia, and comparatively fewer studies from African and other emerging-economy contexts (see Table 2). This imbalance may reflect the stronger representation of countries where waste regulatory frameworks, circular construction policies, research funding and data availability are more established. As a result, the findings should be interpreted as context-sensitive patterns across the reviewed literature rather than universally generalisable claims, particularly for developing contexts with different socio-economic, institutional and regulatory conditions. Finally, there is potential for disciplinary dominance, as the search focuses heavily on construction management, engineering, sustainability and CE perspectives, the findings may underrepresent sociological, behavioural, or purely economic perspectives on stakeholder collaboration. These potential biases were considered and further acknowledged as limitations of the study. The overall identification, screening, eligibility, and inclusion process is presented in Fig. 2.

Document analysis

A structured document analysis was used to extract and synthesise evidence from the 51 included studies. Each paper was read in full and coded using a predefined extraction template aligned with the review objectives. The template captured study characteristics, stakeholder groups, CCWM lifecycle stages, reported roles and responsibilities, engagement/collaboration barriers, affected and influencing stakeholders, and proposed strategies. Key wording and functional descriptions from the source texts were recorded in a comprehensive evidence matrix to provide an audit trail between the original literature and the thematic interpretation. To achieve this, a comprehensive Excel table was prepared to document findings based on the predefined extraction template (see Table S1). Additionally, studies addressing similar objectives were grouped to facilitate the extraction of evidence and interpretations and to avoid forcing studies into unsupported themes, showing that not all studies contributed equally to stakeholder role identification, collaboration barriers, and strategies analysis (see Table 2).

The coding process combined deductive and inductive approaches. Deductive coding was guided by the review objectives, CCWM lifecycle stages and RACI (Responsible-Accountable-Consulted-Informed) governance matrix, while inductive coding captured additional themes emerging from the reviewed studies, particularly collaboration barriers, stakeholder influence and engagement strategies. Inductive themes were retained only where explicitly supported by the source text.

The RACI governance matrix is a widely used tool for clarifying stakeholder roles and responsibilities across project life-cycle stages as Responsible (executes the activity), Accountable (holds final decision authority), Consulted (provides expertise input before implementation), or Informed (kept updated on progress and outcomes) [77]. This was used to assign stakeholder engagement at each concrete project life-cycle stage based on the review findings. Although RACI roles were not explicitly stated in the reviewed studies, the authors analytically inferred them from reported responsibilities, decision-making authority, technical input and information needs. Stakeholders were therefore coded as Responsible, where they executed a task, Accountable, where they held ownership, decision authority of the project phase's success or liability, Consulted, where they provided technical, professional, or subject-matter input before a final decision, and Informed, where they were kept updated on progress, decisions, or outcomes. In ambiguous cases, a conservative coding approach was applied by assigning Consulted or Informed unless direct implementation responsibility or decision authority was clearly supported by the reviewed evidence.

Similarly, engagement and collaboration barriers or strategies were coded only when explicitly identified in the reviewed studies. Stakeholders were classified as affected when they directly experienced a barrier, and as influencing when they had the authority, resources, expertise, or institutional capacity to mitigate it. Barrier themes were counted to identify recurring patterns and inform the analysis and discussion. Finally, to minimize subjective bias and

Table 2 List of studies included in the review

Study	Author (s)	Country	Stakeholder identification and roles	Engagement/ collaboration barriers	Strategies
1	Tam [78]	Australia and Japan	✓		
2	Knoeri, Binder [79]	Switzerland	✓		
3	Hwang and Ng [80]	Singapore	✓		
4	Hradil, Talja [81]	Finland	✓		
5	Domingo and Luo [82]	New Zealand	✓		
6	Muigai [19]	South Africa	✓		
7	Shen, Peng [83]	China	✓	✓	✓
8	Osaily, Copping [84]	United Kingdom	✓	✓	✓
9	Mortensen and Kørnøv [85]	Denmark			✓
10	Ram, Prajapati [86]	India	✓		
11	Andersson, Buser [87]	Sweden	✓		
12	Su [88]	China	✓		
13	Liu, Teng [89]	China	✓	✓	✓
14	Shooshtarian, Caldera [90]	Australia/ Global literature	✓	✓	✓
15	Górecki [91]	Poland	✓	✓	
16	Du, Feng [92]	China	✓	✓	
17	Superti, Houmani [32]	Australia	✓		
18	Ozili and Opene [93]	Nigeria	✓		
19	Zheng, Siddik [94]	Bangladesh	✓		
20	Wang, Wu [95]	China	✓	✓	✓
21	Yu, Yazan [33]	Netherlands	✓	✓	✓
22	Vasconcelos, Silva [96]	Portugal/ Europe		✓	✓
23	Serrano-Bedia and Perez-Perez [97]	Spain	✓	✓	
24	Köhler, Sönnichsen [98]	Denmark		✓	
25	Sepetis [99]	Greece	✓		
26	Keena, Rondinel-Oviedo [100]	Canada	✓	✓	✓
27	Almeida, Vieira [101]	Portugal/general	✓		
28	Shooshtarian, Caldera [102]	Australia	✓		
29	Victar, Perera [41]	Multi-country expert	✓	✓	
30	Ma, Tam [103]	China	✓		
31	Anastasiades, Dockx [31]	Belgium/Flanders	✓		
32	Al-Faesly and Noël [52]	Canada	✓		
33	Agyapong and Tweneboah [104]	Ghana	✓		
34	Harala, Alkki [28]	Finland and Sweden	✓	✓	✓
35	Adhi and Muslim [105]	Indonesia	✓		✓
36	Havinga, Mahdad [106]	UK			✓
37	Shao, Li [107]	China	✓	✓	✓
38	Besklubova, Kravchenko [108]	Hong Kong	✓	✓	✓
39	Riuttala, Harala [21]	Finland	✓		
40	Ma and Hao [8]	China	✓	✓	✓
41	Uotila, Saari [29]	Finland	✓		
42	Li, Li [34]	China	✓		✓
43	Arfa, Lubelli [109]	Netherlands	✓	✓	✓
44	Adabre, Chan [67]	Ghana	✓		✓
45	Wang, Liu [110]	China	✓	✓	✓
46	Song, Hou [111]	China	✓	✓	
47	Rokio, Ahola [30]	Finland	✓	✓	
48	Rataj, Alcorta [112]	Europe	✓		
49	Ababio, Lu [74]	Hong Kong	✓		
50	She, Udawatta [113]	Australia	✓		✓
51	AlJaber, Martinez-Vazquez [27]	United Kingdom	✓	✓	✓

Note: ✓ = key area addressed

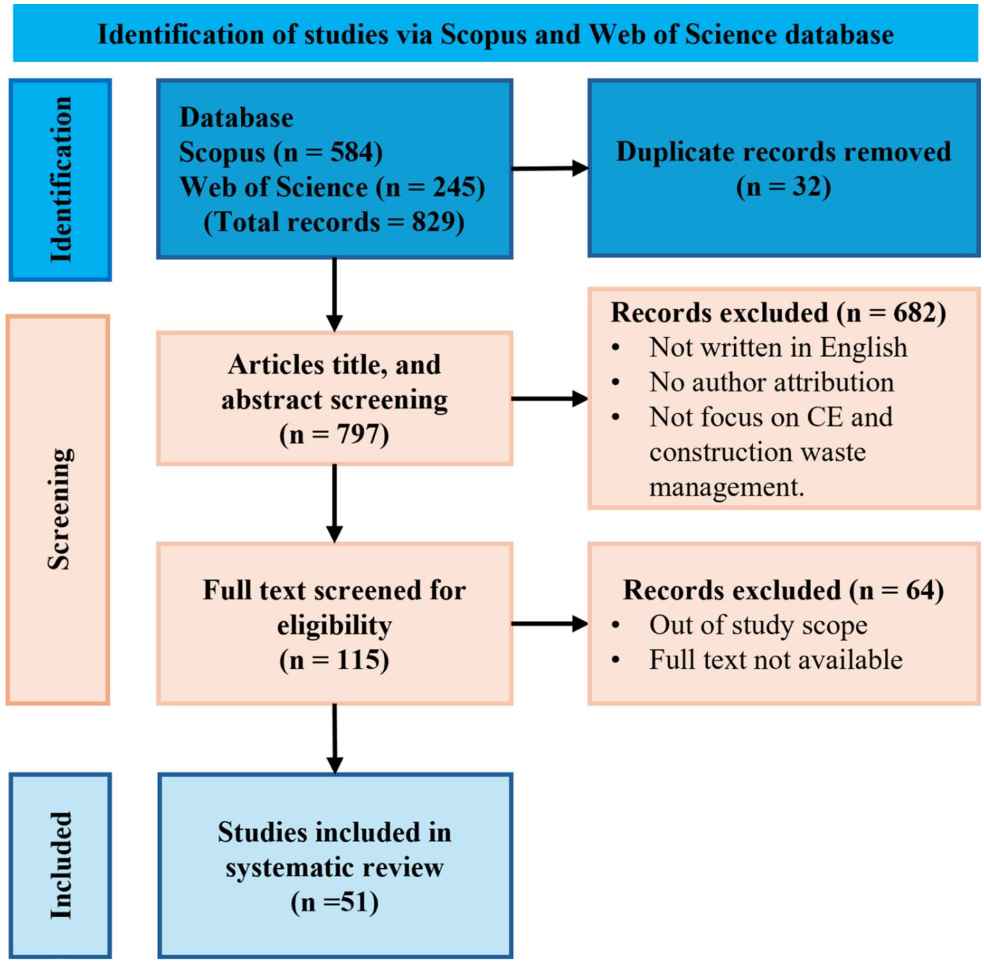

Fig. 2 Selection process of reviewed studies

ensure reproducibility, the coding process was iterative. Two authors independently reviewed the findings to establish a consistent coding framework, and any discrepancies were resolved through discussion, ensuring interpretations remained firmly grounded in the original contexts of the reviewed studies.

Results and discussion

Stakeholder identification and synthesis of roles

Table 3 presents the stakeholder groups collaborating in CCWM, including their subgroups, lifecycle involvement, primary roles and the supporting studies. From the reviewed studies, eleven key stakeholder groups were identified: clients/building owners, consultants, contractors, manufacturers/suppliers, recycling enterprises, government and policymakers, transportation enterprises, financial institutions, public and civil society, academic and research institutions and industry associations.

Building on the extracted synthesis of stakeholder roles in the reviewed study, as shown in Table 3, the RACI governance map in Fig. 3 was developed, showing how responsibilities are distributed across the CCWM lifecycle. It identifies which stakeholder groups are Responsible, Accountable, Consulted, or Informed at each phase, thereby clarifying how different actors contribute to Planning/design; production; construction; operation/use and end-of-life activities. Based on earlier research [28, 30, 74], stakeholders were grouped into primary value-chain actors and supporting actors. The primary value-chain actors (Clients/owners, consultants, contractors, manufacturers/suppliers, logistics providers, and recycling/waste-treatment firms) directly shape material decisions and flow specifications, procurement, handling, dismantling, transport, and processing that determine whether concrete materials are prevented from becoming waste, effectively recovered, and reintegrated into subsequent use cycles. In contrast, supporting actors (Government, finance, academia, industry associations, public and civil society) primarily influence the regulatory, financial, knowledge, and legitimacy conditions that facilitate or constrain implementation.

Table 3 Stakeholder roles in circular concrete waste management (CCWM) across construction lifecycle stages

S/*N*	Stakeholder group	Lifecycle stages involved	Stakeholder subgroup	Roles	Reference codes
1	Government/ policymakers	Planning/design; production; construction; operation/use; end-of-life	Federal/central government, local government; environmental authorities (municipalities)	Formulation of policies, regulations, and standards; provision of economic incentives and funding; provision of infrastructure and technology; supervision and enforcement; stakeholder coordination and public awareness.	[R1-R19, R46]
2	Clients/project owners	Planning/design; production; construction; operation/use; end-of-life	Public and private clients, developers/ investors, asset owners	Circular project initiation, site selection and funding; obtains building permit, defines CE goals; controls procurement and material selection; creates demand for recycled and reusable concrete elements; manages assets and approves end-of-life recovery decisions.	[R1-R2, R4-R5, R8, R10, R13-14, R17-S27]
3	Consultants/ design teams/ professionals	Planning/design; production; construction; operation/use; end-of-life	Architects and designers, structural engineers, quantity surveyors, project managers, procurement specialists, technology consultants, and sustainability experts	Design for circularity; provide technical specification and structural performance assessment; lifecycle planning and sustainability assessment; specify circular materials, planning and project management; digital and technical support for waste management.	[R1, R3-R8, R13, R15, R17, R19-20, R22, R25, R27-R34]
4	Manufacturers and suppliers	Production; construction; operation/use; end-of-life	Concrete producer/supplier (ready-mix, pre-cast concrete)	Produce and supply circular concrete materials and high-performance mixes; integrates recycled content/reclaimed concrete element in new production; standardization of concrete components, provide material specifications, certification and environmental product declarations; provision of storage for reclaimed components.	[R2, R5-R6, R15, R17-R19, R23-R24, R29, R35, R46]
5	Contractors	Construction; operation/use; end-of-life	Construction contractor Demolition contractor	On-site waste control; implementation of material recovery practices; execution of construction, repair, and maintenance works; quality assurance; deconstruction planning; logistics; and documentation of waste information.	[R1-R2, R5-R8, R11-R13, R15-R19, R23, R25-R27, R35-R37, R46]
6	Waste treatment enterprises	End-of-life	Recycling or reuse company	Collection, sorting, and processing of concrete waste into high-quality aggregates; quality assurance and certification; circular concrete material supply; investment in advanced sorting and recycling technologies; documentation of waste records.	[R1-R3, R5-R6, R8-R9, R11-R12, R14, R17, R20, R28, R35, R46]
7	Transportation/logistic enterprises	Production; Construction; end-of-life		Collection, transport, and delivery of concrete waste to treatment facilities; transport recycled concrete products to manufacturers and contractors; waste documentation and traceability support.	[R1, R6-R7, R17, R26]
8	Academic and research Institutions	Planning/design; production; construction; operation/use; end-of-life	Universities, research Institutions,	Knowledge generation and technological innovation support; education and capacity building; quality assurance and performance testing; foster industry and community collaboration.	[R6-R7, R15, R22, R38]
9	Public/civil society	Construction; operation/use; end-of-life	Community, NGO	Promote awareness and behavioural change; advocate for circular concrete waste management policies and practices; community feedback; environmental accountability and public oversight of circular practices.	[R2, R7, R9, R14, R16, R39]
10	Financial institutions	Planning/design; production; construction; operation/use; end-of-life	Banks, insurance companies	Finance circular technologies & infrastructure; risk assessment & insurance support; funding research and pilot projects; incorporate CE criteria and ESG standards into lending conditions and corporate reporting requirements; provides capital and advisory services to circular businesses.	[R14, R19, R40-R45]

Table 3 (continued)

S/*N*	Stakeholder group	Lifecycle stages involved	Stakeholder subgroup	Roles	Reference codes
11	Industry associations	Planning/design; production; construction; operation/use; end-of-life	Professional bodies, concrete and cement associations, waste management associations	Standard-setting and technical guidance; capacity building, knowledge dissemination and professional certification; sustainability report; facilitate collaboration and coordination; policy advocacy and regulatory mediation; circular concrete market development.	[R2, R7]

The map illustrates that CCWM emerges from interdependent, multi-actor interactions rather than isolated interventions by individual stakeholders to preserve material value and continuity. This finding is consistent with established theories of CE transitions, industrial symbiosis and socio-technical transitions, which conceptualize circular outcomes as system-level phenomena shaped by coordination and stakeholder governance across diverse actors rather than individual efforts [67, 73, 85]. It also aligns with empirical studies in circular construction, which show that circularity depends on effective stakeholder governance, collaboration, and information exchange across the project lifecycle [74, 101].

However, the findings point to features that are particularly distinctive in the context of CCWM. As emphasized by Marsh, Velenturf [9], a product-centric perspective is insufficient for concrete circularity, and effective circularity requires integration across material-, product-, and system-level dimensions. Unlike metals or plastics, concrete is chemically irreversible and cannot be fully recycled into its original form, while its composite and heterogeneous nature further complicates material recovery [9]. These challenges are reinforced by the project-based structure of construction, where temporary relationships and fragmented coordination weaken alignment across lifecycle stages [106].

This distinctiveness is especially visible in concrete-element reuse. Harala, Alkki [28] show that reuse changes the conventional sequencing and role boundaries of construction projects. Manufacturers may become involved in demolition planning, marking, storage and refurbishment; engineers may contribute to condition assessment, safety planning and deconstruction mapping; architects must design around available salvaged components rather than beginning from a fully open design brief; and demolition contractors must shift from destructive demolition to careful deconstruction. This illustrates that CCWM does not simply require more collaboration; it requires the reconfiguration of actor roles and responsibilities around the preservation, verification and transfer of concrete material value.

Similarly, RCA-based recycling depends on coordination among designers, producers, construction and demolition actors, recycling facilities, information systems, regulators and policy-support mechanisms [33]. Collectively, these findings suggest that while interdependence is a general feature of CE systems, it is particularly pronounced in CCWM due to material constraints, lifecycle dependencies, and the need for cross-scale integration of strategies. Circular outcomes are therefore tightly coupled to decisions made across the project lifecycle, and the breakdown of coordination at any point may undermine the wider CCWM system.

The RACI further reveals several important coordination gaps that may weaken CCWM implementation. First, enforcement responsibilities are concentrated among government/policymakers across multiple phases, indicating a strong reliance on regulatory oversight to drive compliance, suggesting more distributed accountability and stronger industry-led mechanisms. Second, key operational actors, particularly construction and demolition contractors and recyclers, appear weakly engaged at the design stage. This limits the integration of site-level and end-of-life insights into circular design decisions and increases the risk of designs that are difficult to dismantle, document, or recover efficiently. Third, waste documentation and traceability responsibilities are dispersed across contractors, recyclers, and logistics providers, which may lead to fragmented information flows and inconsistent records unless supported by interoperable data systems and clearly defined reporting arrangements. Finally, sustainability assessments are concentrated among consultants and academia, while contractors and suppliers appear less engaged in ongoing performance assessment, indicating a gap between technical evaluation and operational decision-making. Together, these findings point to opportunities to strengthen engagement, feedback loops, and collaboration to support a more integrated circular governance structure. The specific roles of each stakeholder group are discussed in detail in the following subsection.

Reference codes [R1] Li et al. (2024); [R2] Ram et al. (2019); [R3] Shooshtarian et al. (2022); [R4] Ababio et al. (2025); [R5] Almeida et al. (2022); [R6] Liu et al. (2020); [R7] Harala et al. (2023); [R8] Ma and Hao (2024); [R9] Wang et al. (2024); [R10] Keena et al. (2022); [R11] Saeed and Khudhair (2024); [R12] Su (2020); [R13] Knoeri et al. (2011); [R14] Domingo and Luo (2017); [R15] Matias Rokio et al. (2024); [R16] Du et al. (2020); [R17] Ma et al.

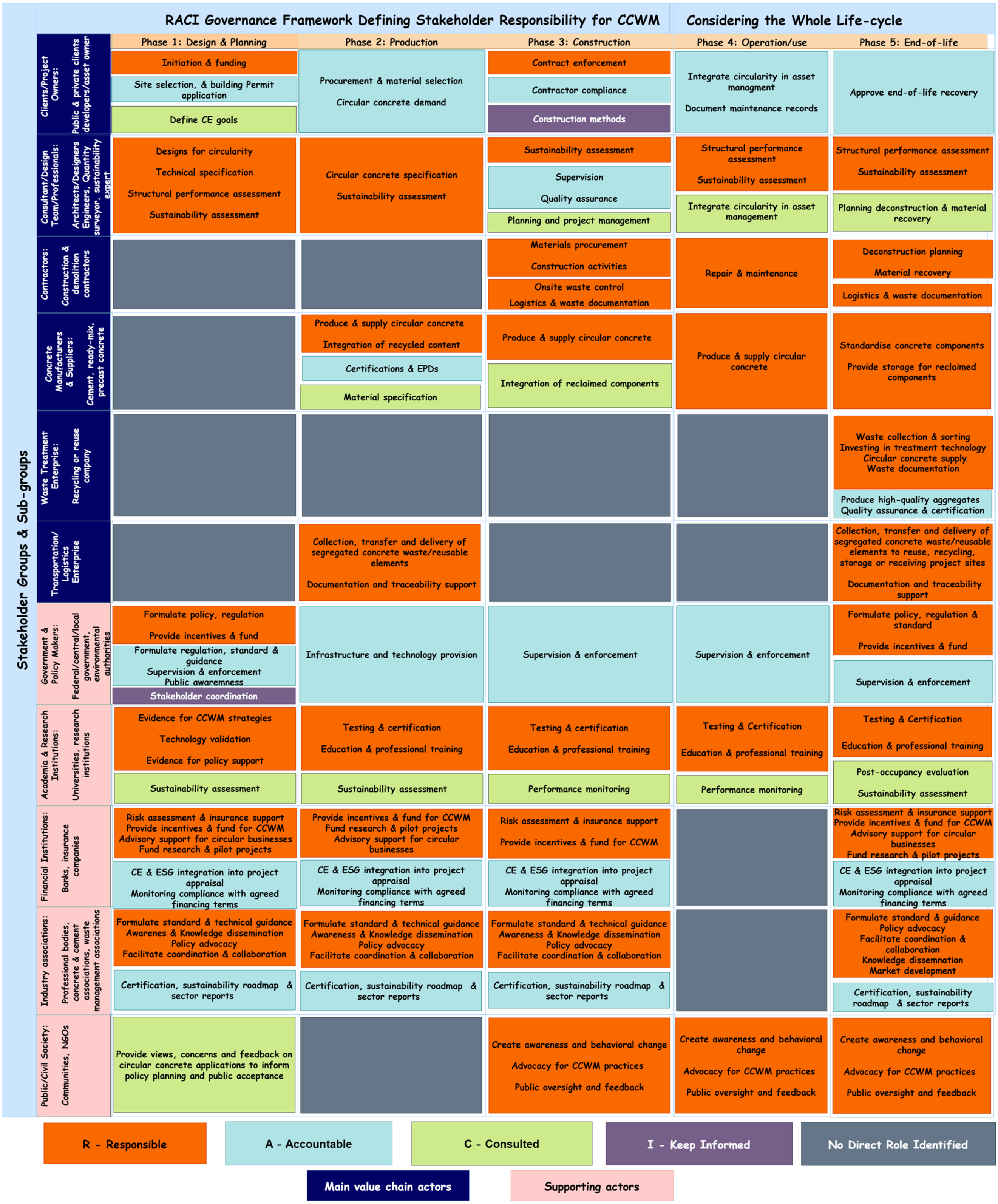

Fig. 3 A RACI governance framework defining stakeholder responsibilities for CCWM across the whole life-cycle stages of concrete construction projects

(2023); [R18] Al-Faesly and Noël (2023); [R19] Anastasiades et al. (2023), [R20] Tam (2009); [R21] Shooshtarian et al. (2022); [R22] Adabre et al. (2024); [R23] Riuttala et al. (2024); [R24] AlJaber et al. (2025); [R25] Muigai (2018); [R26] Wang et al. (2021); [R27] Hradil et al. (2014); [R28] Song et al. (2024); [R29] Uotila et al. (2024); [RR30] Hwang and Ng (2013); [R31] Arfa et al. (2024); [R32] Górecki (2020); [R33] Victar et al. (2023); [R34] Superti et al. (2021); [R35] Yu et al. (2021); [R36] Osaily et al. (2019); [R37] Andersson et al. (2019); [R38] Serrano-Bedia and Perez-Perez (2022); [R39] Adhi and Muslim (2023); [R40] Sepetis (2022); [R41] Ozili and Opene (2021); [R42] Shen et al. (2018); [R43] Agyapong and Tweneboah (2023); [R44] Rataj et al. (2025); [R45] Zheng et al. (2021); [R46] Besklubova et al. (2023).

Primary value-chain actors

Clients and project owners

Clients and building owners play a pivotal role in CCWM across the project life cycle, as their decisions establish the strategic, financial, and organizational conditions under which circular strategies are implemented. They include government agencies, real estate developers, corporate institutions, and individual homebuilders, each exerting a different level of influence on project direction [52, 114].

At the design and planning stage, clients define project objectives and priorities by allocating funds, setting sustainability targets, and embedding CE requirements such as life-cycle costing, recycled content, design-for-disassembly, and reuse considerations into briefs, tenders, and procurement frameworks [27]. Harala, Alkki [28], for instance, show that the client was responsible for "finding a suitable pilot site, applying for a building permit, and representing the client's point of view", revealing the client's role in initiating and shaping circular project requirements. Similarly, Riuttala, Harala [21], in a concrete reuse case study, show that the client/project manager was involved in managing the "economic feasibility" of building component reuse. These early decisions strongly influence the extent to which designers and contractors can integrate circular concrete solutions [34, 74]. During production and construction, clients influence CCWM through procurement choices, contract enforcement and circular guideline requirements, shaping material selection, contractor compliance and demand for recycled or reusable concrete materials [67, 78]. Ma and Hao [8] also noted that green procurement is difficult without client willingness, highlighting the importance of the client role in reducing demand uncertainty and encouraging downstream actors to adopt circular practices.

During the operation and use phase, clients influence circularity through asset management decisions, including maintenance, repair, refurbishment, and adaptive reuse strategies that extend structural service life and delay demolition [69]. Uotila, Saari [29] state that "all the information should be saved by the building owner," including information on operating conditions, adjustments, repairs and later modifications. This indicates that building owners have an important information-stewardship role in preserving material value for future reuse or high-quality recycling.

At the end-of-life stage, clients and owners approve recovery pathways by supporting selective demolition approaches, commissioning audits, and engaging qualified recovery actors. However, their engagement is often influenced by knowledge, perceptions and expectations [90], underscoring the need for targeted education, demonstration of successful circular projects and supportive legislative and incentive mechanisms [8]. These functions reveal that within the RACI framework, clients and building owners can be positioned as Accountable actors where they select suitable project sites, obtain building permits, define project objectives, approve procurement requirements, enforce contractual obligations and authorise recovery pathways. They may also act as Responsible actors where they directly initiate circular projects, allocate funding, maintain building information, or implement asset-management decisions that preserve concrete material value. Their role shifts to Consulted, where their CE requirements, project priorities, budget constraints, reuse preferences or acceptance criteria are sought by consultants, contractors, or manufacturers to guide technical decisions. They are informed where circular activities are implemented by other actors but require client or owner awareness, approval updates or record-keeping across the project lifecycle. As such, client function both as key enablers and potential gatekeepers of CCWM, with their engagement playing a decisive role in whether circular strategies are fully realized across the project life cycle.

Consultants (design teams/professionals)

Consultants and built-environment professionals, including architects, engineers, quantity surveyors, project managers, procurement specialists, and sustainability or CE consultants, play a central role in translating client requirements into circular design strategies and advising on material choices [34, 52]. Their technical decisions determine concrete waste generation, reuse potential, safety, and material traceability.

During the design stage, architects play a central role in educating the clients, implementing a waste minimization strategy and improving design [115]. They design structures to incorporate recycled concrete, reclaimed components, and other green materials, alongside selecting appropriate structural systems and construction approaches such as optimized structural design, modularization, standardization, reversible connections, and design-for-disassembly (DfD), to enhance material efficiency, reduce waste generation, and enable the future recoverability of concrete elements [8, 86, 116]. Superti, Houmani [32] further indicate that architects are expected to be "proactive in proposing ecological measures to clients, as part of their ethical and professional responsibility" in promoting circular design, while Uotila, Saari [29] demonstrate that designers and structural engineers contribute to managing or advising on building lifecycle data needed to assess future reuse and recovery potential. Engineers also support these choices by ensuring technical feasibility, durability and safety of the circular initiatives [28], sustainability and CE consultants contribute through design reviews, circular performance evaluation, and compliance with regulatory requirements [91], while quantity surveyors assess financial implications through life-cycle costing of alternative circular design options [41]. Technology consultants can also support CCWM by providing digital solutions for sustainability tracking, procurement processes, material passports, smart contracts and data transparency across the project lifecycle [74].

In the construction phase, consultants contribute through supervision, cost control, procurement support, and quality assurance [74]. Project and procurement managers coordinate stakeholder inputs, manage risks, and ensure that circular specifications such as recycled content requirements or waste-management plans are implemented as intended without undermining the quality, time and cost performance of the project [80]. During the use and operation phase, consultants contribute to condition assessments of existing concrete structures, specification of eco-efficient repair strategies and retrofitting, that preserve structural performance and material value over time, enabling service-life extension and improving the feasibility of future reuse or high-quality recycling [19, 117].

At the end-of-life, consultants facilitate informed recovery decisions by providing as-built documentation, material specifications, and technical guidance that support selective demolition, component assessment, reuse of concrete elements, and recycled concrete [28, 91]. Riuttala, Harala [21] state that the role of structural designers in concrete reuse is through element inventory, condition assessment, structurally safe deconstruction sequencing and design for the receiving building. However, consultants' influence at end-of-life is often limited where recovery, reuse and documentation requirements were not integrated earlier in the design process [30].

Overall, consultants mediate between clients, regulators, contractors, manufacturers and suppliers by balancing technical feasibility, structural safety, cost implications, regulatory requirements and sustainability objectives [67, 109]. Their effectiveness depends not only on professional competence but also on interdisciplinary coordination, alignment with client priorities, access to reliable data and supportive policy and regulatory frameworks [90, 118]. These roles support the classification of consultants in the RACI mapping mainly as Responsible for preparing technical designs, specifications, and assessments and may be Accountable to the client for the quality, safety and compliance of the technical outputs. They are also Consulted where their expertise informs client decisions, contractor implementation or material planning and recovery strategies.

Contractors (construction and demolition contractors)

Contractors influence the construction, operation and end-of-life management of concrete structures. Construction contractors (builders) contribute to CCWM through their decisions on construction methods, material procurement, and on-site waste practices. As major generators of concrete waste, they influence the quality and quantity of materials available for reuse and recycling [86]. Their responsibilities include adopting low-waste construction technologies (e.g., prefabrication and smart construction), improving site organization, segregating concrete waste, and implementing on-site reuse or recycling procedures [8, 34].

During the operation and use phase, construction contractors also support the maintenance of concrete structures by executing repair and durability works, implementing maintenance plans, maintaining traceability records, and selecting durable materials that enhance the service life and the future reuse potential of concrete components. Additionally, their acceptance of recycled aggregates and reclaimed concrete components shapes market demand, which often depends on technical performance and cost considerations [34, 52]. However, they are more driven by direct economic benefits than environmental objectives, i.e., contractors' decision-making behaviours depend on comparisons between the costs of legal waste treatment and the penalties for illegal dumping [92, 108].

Furthermore, at end-of-life, demolition contractors develop methodologies, risk assessments, safety measures, inventory and logistics plans that maximise component recovery [28, 84]. Riuttala, Harala [21] further noted that they are expected to provide "element transportation, tracking, and element inventorying services". However, their influence is strengthened when engaged early in the design stage, where they can integrate end-of-life considerations, advise on material recovery strategies, and guide design-for-deconstruction (DfD) efficiency [84]. Similarly, the early involvement of construction contractors enhances circular design decisions by providing useful information about material availability, construction sequencing, prefabrication potential, buildability, and resource efficiency [119].

Overall, contractors act as operational enablers of CCWM, with responsibility for construction practices, repair works, selective deconstruction, on-site sorting, material handling, temporary storage, site waste management, logistics coordination and documentation of concrete waste flows.

Concrete manufacturers and suppliers

Manufacturers and suppliers occupy a pivotal position in CCWM by translating recovered concrete materials and circular design intent into market-ready products. AlJaber, Martinez-Vazquez [27] describe them as actors “responsible for producing and supplying the materials and components used in construction”, thereby highlighting their crucial role in shaping the material supply chain. As producers of ready-mix concrete (RMC), precast elements, and construction materials, they play a critical role in integrating recycled concrete aggregates (RCA), recycled fine aggregates (RFA), and recycled concrete fines into new concrete production [33, 52]. Their capacity and willingness to adapt manufacturing processes to incorporate recycled inputs and accommodate reclaimed components directly influence the viability of circular construction markets [100].

Beyond primary production, manufacturers increasingly contribute to higher-value circular strategies by refurbishing, testing, and certifying salvaged concrete elements, enabling their safe re-entry into the construction market [21]. Harala, Alkki [28] demonstrate that concrete element manufacturers “expand their conventional production role by participating in demolition planning, marking, storing and refurbishing detached elements.” This evidence highlights their role not only as producers, but also as quality enablers and information providers within the circular concrete value chain. Uotila, Saari [29] further mention that manufacturers provide important product and material data, including “producer of component”, “time of production”, “useful life”, “material certificates”, and “material information”, which other stakeholders require for assessment, traceability and future reuse. They shape circular outcomes through their logistics, inventory management, and sourcing strategies [33]. This evidence highlights their role not only as producers, but also as quality enablers and information providers within the circular concrete value chain.

Therefore, concrete manufacturers and suppliers are classified as Responsible actors where they produce, refurbish, document and supply circular concrete products, and as Accountable for the quality and performance reliability of those products. They also act as Consulted stakeholders where their technical input is needed on material availability, specifications and feasibility.

Waste treatment enterprises

Waste treatment enterprises, also known as recycling enterprises, play a pivotal role in CCWM, particularly during the end-of-life and material recovery stages of the project life cycle. At the end-of-life stage, recycling enterprises are responsible for receiving concrete waste from demolition and construction sites and for processing it into high-quality secondary materials [34, 69]. Yu, Yazan [33] show that “defective concrete waste from production processes and construction and demolition waste from project sites are transported to recycling factories,” where recyclers provide the technology for “separating and recycling concrete waste.” This evidence supports the interpretation that recycling enterprises act as anchor actors between waste providers and material receivers. They invest in advanced sorting, crushing, separation, and recycling technologies to enable a shift from low-value, volume-based waste treatment toward quality-oriented value recovery, supporting higher-value applications in new construction [89, 110]. In doing so, they directly determine both the quantity and quality of recycled concrete materials re-entering the construction supply chain [8]. However, their operational performance is highly sensitive to waste availability, market demand, technical capacity, operational cost, and incentive support [110, 111]. Despite these constraints, their role is increasingly important for enabling high-value recycling, reducing landfill disposal, and ensuring regulatory compliance within CCWM systems [101]. Strengthening their contribution, therefore, requires a supportive regulatory framework, stable demand, clear material standards, and integration with upstream stakeholders throughout the project life cycle. These functions support their classification as Responsible actors, where they receive, document, sort, process and recycle concrete waste, as well as where they invest in advanced waste treatment technologies. They are also Accountable actors for the quality of recycled concrete products they produce.

Transportation/Logistics enterprises

Transportation enterprises play a critical enabling role in CCWM by facilitating the movement of concrete materials across the construction value chain. Liu, Teng [89] describes transportation enterprises as a “connecting link in the industry chain” that “transports the waste to the destination,” while also coordinating material flows between upstream waste generators and downstream recycling or reuse actors.

During construction and end-of-life, transport and logistics enterprises are responsible for the timely collection, hauling, and delivery of segregated concrete waste streams and reusable elements to appropriate reuse or recycling destinations [33]. Their operational performance directly influences recovery efficiency, cost, and environmental outcomes. Improper handling, poor segregation, or mixed transport can contaminate concrete waste, degrading material quality and reducing its suitability for high-value recycling or reuse [28, 89]. Similarly, logistics-related factors such as transport distance, routing efficiency, vehicle type, and load optimization significantly affect fuel consumption, greenhouse gas emissions, and the overall life-cycle impacts of recycled and reused concrete materials [120, 121]. Thus, the need for proximity-based sourcing, coordinated logistics, and optimized routing improves carbon efficiency and enhances the economic competitiveness of CCWM [122].

Transportation enterprises also support CCWM by collaborating with contractors, recycling companies and waste service authorities to document the origin, quantity, and destination of materials, thereby strengthening traceability, transparency, and successful reuse of concrete [103]. However, despite their contribution, they are faced with persistent challenges, including high upfront investment costs, limited financial incentives, uneven service demand, and underdeveloped circular logistics infrastructure [34, 123]. Strengthening their contribution to CCWM, therefore, requires better contractual alignment, targeted incentive mechanisms, and continued technological innovation to optimize logistics performance, reduce emissions, and preserve material value across the project life cycle. This evidence indicates that transportation/logistics enterprises operate as Responsible actors for collecting, loading, transferring and transporting segregated concrete waste streams or reusable elements to designated reuse, recycling or disposal facilities.

Supporting actors

Government and policymakers

Government and policymakers, including national and local governments, regulatory agencies, and environmental authorities (municipalities), are the central institutional actors in CCWM. Ababio, Lu [74] identify government as a key stakeholder in "policy planning," noting its strategic role in leading national and regional policy agendas and using legitimacy and power to influence procurement decisions. In CCWM, this role is reflected in the establishment of regulatory and standards frameworks that reduce uncertainty and build confidence in secondary concrete products. These include enforceable requirements for source segregation, deconstruction and demolition permitting, waste reporting, alongside performance-based standards and design guidance supporting the safe use of recycled and reused concrete elements [30, 124].

Beyond regulation, governments influence stakeholder behaviour through economic incentives, procurement requirements and market-support mechanisms. Li, Li [34] state that, "as the regulator of the market, the government formulates economic incentive policies" to support stakeholders involved in recycled concrete utilisation. Similarly, Yu, Yazan [33] emphasise the government's "leading role" in providing "external forces" and "institutional power," including targeted subsidies, to reduce business risks associated with recycling activities. Ma and Hao [8] further demonstrate that government involvement cuts across several strategies, including standards for secondary materials, incentives for secondary material use, waste-management information technologies, recycling logistics systems, landfill-cost mechanisms and legislation for C&D waste recovery. These measures help shift behaviour from disposal towards recovery by stabilising demand, encouraging private investment and improving confidence in circular concrete markets.

Governments also support CCWM through monitoring systems, reporting requirements, information infrastructure, pilot projects, awareness campaigns and multi-stakeholder platforms, which can strengthen accountability and reduce information asymmetry across the value chain [34, 89]. Overall, governments function as policymakers, regulators, supervisors and system leaders, shaping the governance environment within which other stakeholders operate [110]. However, their effectiveness may be constrained by political resistance, competing priorities and limited awareness or understanding of circular economy principles [125]. Accordingly, these functions position government/policymakers mainly as Accountable actors where they set regulations, standards, incentives, procurement requirements and enforcement mechanisms; as Responsible actors where they directly implement monitoring systems, public procurement programmes or pilot initiatives; and as Consulted actors where regulatory guidance or approval is required for CCWM decisions.

Financial institutions

Financial institutions, including commercial banks, development finance institutions, and institutional investors, play a pivotal enabling role in CCWM by directing capital flows toward circular practices and technologies. Rataj, Alcorta [112] note that financial institutions contribute to CE transitions, "by providing funding to CE business models (CEBM)". Although often less visible than material-chain actors, they strongly influence the feasibility and pace of CCWM adoption through financing conditions, risk assessment, and investment priorities [126].

A frequently cited barrier to CCWM implementation is the high upfront investment required for advanced crushing and sorting facilities, selective demolition equipment, and innovative recycling and recovery technologies. Financial institutions help bridge this gap by offering tailored financial instruments such as green loans, sustainability-linked bonds, and blended finance that link financing terms to environmental performance and recovery outcomes, thereby incentivizing waste minimization and high-value material recovery [74, 93]. Sepetis [99] similarly explains that financial stakeholders support sustainable finance and CE transitions by providing sustainable businesses with easier and lower-cost access to capital.

International financiers illustrate this role in practice. For instance, the European Investment Bank (EIB) committed over USD 10 billion through its Joint Initiative on Circular Economy to provide loans, equity investments, guarantees, and advisory services for circular projects in construction and related sectors [112]. Similarly, the International Finance Corporation (IFC) channels green bonds and concessional loans toward sustainable waste and recycling projects, supporting initiatives that divert concrete from landfills and promote reuse. Such mechanisms reduce capital costs, de-risk early-stage investments, and improve the bankability of CCWM initiatives.

Beyond project-level financing, financial institutions promote circular initiatives by integrating CE principles and environmental, social, and governance (ESG) criteria into investment appraisal, due diligence and risk-screening processes [99]. This alignment helps mitigate exposure to resource scarcity, carbon regulation, and transition risks while improving long-term risk-adjusted returns [126]. In CCWM, financial institutions can therefore strengthen project bankability by requiring evidence of material traceability, lifecycle benefits, regulatory compliance and reliable demand for recycled or reused concrete products. Lastly, financial institutions collaborate with governments and regulators to develop harmonized standards, incentives, and guidance for circular finance in construction, while providing advisory support to circular businesses [99, 112].

In RACI terms, financial institutions are mainly positioned as Responsible actors where they provide finance, guarantees, insurance, or advisory support for circular businesses and CCWM-related projects. They are Accountable where they integrate CE and ESG criteria into project appraisal and monitor compliance with agreed financing terms.

Academic and research institutions

Academic and research institutions, including universities, research centres, and technical laboratories, play a foundational enabling role in CCWM by generating knowledge, validating technologies, and supporting capacity building across the project life cycle. Bajare, Zsembinszki [125], emphasized the role of academic research in advancing circular economy knowledge, technologies, innovations and best practices. Similarly, Ababio, Lu [74] indicate that research institutions can support policy planning by providing knowledge that helps government bodies embed circularity principles into broader strategies and regional roadmaps. In CCWM, this role is reflected in the development of evidence-based guidelines for CCWM strategies, including the use of secondary concrete products, circular business models, advanced construction and recovery technologies, and life-cycle assessment (LCA) frameworks [21]. Their strategic position enables them to catalyze circular transitions at multiple levels, from local communities to national policy frameworks, making them essential actors in promoting the adoption, scaling, and societal acceptance of CCWM practices.

Across the construction, operation, and end-of-life stages, academic and research institutes contribute through material testing, performance assessment, certification support and evaluation of reuse and recycling options [28]. In several documented cases, universities have acted as neutral testing and coordination bodies in concrete reuse and recycling projects, assessing environmental, economic, and social feasibility in collaboration with industry and public-sector actors [28, 67]. For example, Harala, Alkki [28] show that, in a Finnish reuse pilot, the local university acted as both coordinator and research organisation, supporting assessment of environmental, business and social acceptability. In another Swedish pilot, the university's role expanded further because no architectural firm was involved; it therefore performed design-related functions, including responsibility for the design and digital model of the pilot building [28].

Beyond their technical contributions, academic institutions shape CCWM through education and professional training by embedding CE principles into engineering, architecture, and construction curricula [97]. This educational role is essential for developing the competencies required to operationalize circular strategies and for addressing skills gaps across the construction value chain. However, limited funding, research gaps, and the time required to translate academic findings into practical applications can present obstacles [125]. This evidence indicates that academic and research institutions can be positioned as Responsible actors where they directly conduct educational and professional training, material testing, performance assessment, pilot-project coordination or design-related research activities, and as Consulted actors where they provide research evidence, technical advice, and performance monitoring.

Public and civil society

Public and civil society stakeholders, including community groups, end-users and non-governmental organizations (NGOs), play an important societal role in shaping attitudes, perceptions, and behaviours that influence the adoption of CCWM. Empirical studies consistently identify stakeholders' perception and resistance to change as major barriers to CCWM practices, largely due to limited understanding of their environmental and economic benefits compared to conventional construction practices [8, 30]. Civil society actors can help address these barriers by raising awareness, advocating responsible construction practices and promoting selective demolition, repair, reuse and recycling as socially valuable alternatives to disposal [35, 92, 110].

Their role is evident in policy acceptance, market demand and public accountability. Ababio, Lu [74], recognise local communities as key stakeholders in policy planning because they are affected by, and have an interest in, the outcomes of circular procurement policies; their involvement therefore helps ensure that circular policies respond to local needs and gain social acceptance. As end-users, the public also influences demand for recycled concrete products through their quality perception and willingness to pay for recycled products [34]. Similarly, Wang, Liu [110] indicate that the public can act as both supervisor and motivator in construction waste recycling, as public reputation pressure may influence corporate and government behaviour.

However, public and civil society participation depends on access to clear information, guidance and awareness programmes. Adabre, Chan [67] suggest that public understanding of CE practices depends partly on prior knowledge dissemination by professionals and higher education institutions. This indicates that public and civil society stakeholders are not only contributors to advocacy and accountability, but also recipients of information, manuals, awareness campaigns and guidance needed to support informed participation [125]. Within the RACI mapping, public and civil society stakeholders are positioned as Responsible actors where they promote awareness, advocate for CCWM policies and practices, provide community feedback, support environmental accountability and provide public oversight of circular practices. They are positioned as Consulted actors where their views, concerns and acceptance feedback inform policy planning and the social acceptability of CCWM practices.

Industry associations

Industry associations, including professional bodies, construction federations, cement and concrete organizations, and waste management associations, play a critical intermediary role in CCWM by coordinating industry action, translating policy and research into practice, and supporting sector-wide capacity building.

A core function of industry associations is the development and dissemination of technical guidance, standards, and best-practice frameworks through workshops, guidelines, conferences, and outreach activities. Harala, Alkki [28] identify industry associations as "supporting actors" in a concrete reuse pilot, noting their responsibility for "the communication and visibility of the project," such as the role of Green Building Council Finland. This illustrates how associations can increase awareness, communicate project lessons and improve stakeholder confidence in circular concrete practices. Sector organisations, such as cement and concrete associations, contribute to CCWM through activities such as industry roadmaps, low-carbon concrete codes, environmental product declaration guidance, certification schemes, carbon-performance reporting and training initiatives [127]. These efforts reduce uncertainty around technical performance and regulatory compliance, enhance market confidence, and promote more consistent adoption of CCWM strategies.

Beyond technical guidance, industry associations facilitate collaboration and collective action by creating platforms for knowledge exchange, pilot projects, and sector-led agreements that align multiple stakeholders around shared waste reduction and decarbonization goals [86, 128]. Lastly, industry associations act as policy intermediaries, representing sector perspectives in regulatory consultations and helping bridge gaps between regulatory ambition and practical implementation. Therefore, industry associations can be positioned as Responsible actors where they formulate and disseminate standards, technical guidance or best-practice frameworks, organise knowledge-sharing, training, certification support, policy advocacy and stakeholder coordination activities. They are also Accountable for the credibility, quality and governance of association-led certification schemes, sustainability roadmaps and sector reports.

Barriers to stakeholder engagement and collaboration

Despite growing recognition of the importance of stakeholder engagement and collaboration for CCWM, the literature consistently highlights a range of interrelated barriers that constrain effective engagement and collaboration (see Table 4). Unclear roles, weak early engagement, and the undervaluation of stakeholder expertise constitute the most frequently reported challenge in the literature (frequency = 7). Multiple studies highlight persistent ambiguity in stakeholder roles, responsibilities, and decision rights across the project life cycle, particularly regarding accountability for circular objectives, material recovery planning, and cross-actor coordination [98, 103]. This lack of role clarity may lead to circular responsibilities being implicitly assigned or overlooked altogether, thus impacting implementation. For instance, Osaily, Copping [84] emphasised that demolition contractors' practical knowledge is frequently undervalued or dismissed by other professionals, partly due to the sector's limited formal research culture and academic recognition. Similarly, Górecki [91] show that the lack of formal acknowledgment of CE expert roles weakens their influence in early-stage decision-making. Collectively, these dynamics marginalize practice-based expertise, constrain knowledge exchange and co-creation, and undermine integrated life-cycle decision-making essential for effective CCWM.

Table 4 Perceived barriers to effective stakeholder engagement and collaboration in CCWM

Code	Barriers	Frequency	References
CB1	Financial and cost constraints	3	Osaily, Copping [84]; Serrano-Bedia and Perez-Perez [97]; AlJaber, Martinez-Vazquez [27]
CB2	Lack of economic incentives and policy support	3	AlJaber, Martinez-Vazquez [27]; Liu, Teng [89]; Köhler, Sönnichsen [98].
CB3	Regulatory gaps, enforcement and supervision gaps	5	Liu, Teng [89]; AlJaber, Martinez-Vazquez [27]; Vasconcelos, Silva [96]; Arfa, Lubelli [109]; Yu, Yazan [33].
CB4	Organizational constraints: time, capacity and project size	3	Köhler, Sönnichsen [98]; Yu, Yazan [33]; Osaily, Copping [84].
CB5	Cultural resistance and linear industry practices	3	Osaily, Copping [84]; AlJaber, Martinez-Vazquez [27]; Köhler, Sönnichsen [98].
CB6	Trust and commitment issues	3	Yu, Yazan [33]; Köhler, Sönnichsen [98]; Osaily, Copping [84].
CB7	Unclear roles, weak engagement, and undervalued expertise	7	Osaily, Copping [84]; AlJaber, Martinez-Vazquez [27]; Górecki [91]; Köhler, Sönnichsen [98]; Liu, Teng [89]; Arfa, Lubelli [109]; Du, Feng [92].
CB8	Conflicting priorities and misaligned understanding of circularity	5	AlJaber, Martinez-Vazquez [27]; Arfa, Lubelli [109]; Du, Feng [92]; Vasconcelos, Silva [96]; Köhler, Sönnichsen [98].
CB9	Poor communication and limited knowledge sharing	5	AlJaber, Martinez-Vazquez [27]; Liu, Teng [89]; Yu, Yazan [33]; Köhler, Sönnichsen [98]; Serrano-Bedia and Perez-Perez [97].
CB10	Lack of awareness of circular concepts and the associated benefits	2	Osaily, Copping [84]; AlJaber, Martinez-Vazquez [27].

Regulatory and institutional factors exert a second, distinctive influence on collaboration quality (frequency = 5). Inconsistent or underdeveloped regulations, fragmented standards for concrete element reuse and recycled concrete, poor enforcement and supervision, complex administrative procedures and the absence of a stakeholder engagement framework discourage collaboration [27, 89, 129]. These conditions increase perceived risk and weaken stakeholder confidence, particularly in reuse-and refurbishment-oriented strategies that require cross-sector coordination and regulatory approval [96, 109].

Closely linked to regulatory issues are conflicting priorities or goals and misaligned interpretations of circularity (frequency = 5). Stakeholders often approach CCWM from divergent interests shaped by preservation objectives, commercial imperatives, community expectations, and regulatory requirements [109]. For example, clients typically prioritize cost efficiency and project timelines, governments focus on broader environmental and socio-economic benefits [130], while contractors who generate the majority of concrete waste may prioritize cost-minimizing practices, including illegal dumping, especially in contexts where enforcement is weak [92]. These competing priorities can lead to inconsistent objectives, fragmented decision-making, and limited willingness to collaborate, particularly where mechanisms for aligning responsibilities are absent [98].

Compounding these challenges are poor communication and limited knowledge sharing (frequency = 5). The lack of structured communication channels and shared information platforms restricts transparency across the concrete life cycle [89]. Limited access to material inventories, certification data, recovery outcomes, and performance feedback undermines trust and prevents learning and timely decision making across stakeholder groups [131]. Additionally, organizational constraints related to time pressure and firm size make early stakeholder engagement and collaboration difficult (frequency = 3), particularly in small and medium-sized enterprises [33, 84].

Furthermore, financial and cost constraints remain influential. Cost-related barriers (frequency = 3) hinder early engagement and long-term investment in circular practices, as upfront costs associated with circular practices like selective demolition, advanced recycling technologies, material testing, and digital documentation deter participation where returns are uncertain or delayed. Osaily, Copping [84] demonstrates that clients are frequently reluctant to fund early collaboration, while contractors, recyclers, and transport providers tend to base participation decisions on immediate cost–benefit considerations, especially where landfill fees are low, or enforcement is weak [84, 97]. Closely related is the lack of economic incentives and policy support (frequency = 3), which reduces motivation for stakeholders. AlJaber, Martinez-Vazquez [27] highlighted that contractors and suppliers are unlikely to engage collaboratively without client-driven incentives or policy mandates rewarding CE performance.

Cultural resistance and entrenched linear industry practices further affect engagement and collaboration (frequency = 3). Studies emphasized that the construction industry is known for its resistance to change and accepting new concept [84]. Stakeholders often perceive circular strategies as risky, disruptive, or incompatible with established workflows. These attitudes are reinforced by trust and commitment issues (frequency = 3), where limited prior collaboration, competitive market structures, and unclear benefits reduce willingness to share information or invest in joint solutions.

Finally, limited awareness of CCWM concepts and associated benefits (frequency = 2) also remains a foundational constraint. Insufficient understanding of CCWM strategies, performance potential, and long-term value creation contributes to conservative decision-making, resistance to change, and weak demand, particularly among clients and end users [27, 84].

Based on these findings, this study illustrates how the perceived barriers to stakeholder collaboration and engagement affect different stakeholder groups, distinguishing between those most affected and those with the capacity to address them, as presented in Fig. 4. The figure shows that stakeholder engagement challenges in CCWM are not uniform but relational in nature. Financial and cost-related constraints, weak incentives, regulatory, and organizational constraints mostly affect value-chain actors such as clients, contractors, waste treatment enterprises, manufacturers and transportation/logistics enterprises. They also affect academic/research institutions where limited funding restricts knowledge translation. However, their mitigation often requires support from government/policymakers, financial institutions, industry associations and clients through incentives, procurement decisions, regulatory guidance, funding mechanisms and market creation.

Figure 4 also reveals that some barriers are internal to the stakeholder groups that experience them. For example, cost concerns among clients, and time, capacity and technical limitations among contractors, manufacturers, recyclers and academic institutions, suggest that external incentives alone may be insufficient without internal organisational commitment. Liu, Teng [89] indicates that government subsidies may not reduce recycling costs effectively unless recycling enterprises also invest in operational and technological improvements. Similarly, Riuttala, Harala [21] suggest that construction businesses with existing machinery, facilities and processes that can be adapted to deconstruction, refurbishment or design for reuse are likely to face lower transition costs than firms without such capabilities. This implies that policy incentives can enable CCWM, but cannot replace firm-level process upgrading and capability development within the circular concrete value chain.

Conversely, barriers related to trust, unclear roles, weak engagement and undervalued expertise mainly affect primary value chain actors whose practical knowledge is needed for circular design, recovery, logistics, processing and material supply. However, mitigation depends on actors with governance and coordination capacity, particularly clients/project owners, government/policymakers and industry associations, which can clarify responsibilities, strengthen engagement processes and formalise stakeholder roles.

Barriers such as misaligned priorities, cultural resistance, poor communication and limited awareness and understanding of circularity cut across both primary and supporting actors, indicating deeper governance and coordination deficiencies. Harala, Alkki [28] emphasized that when core ecosystem actors, such as demolition companies, engineering and architectural firms, concrete manufacturers and construction companies, demonstrate that reused concrete elements are technically safe, legally viable and commercially profitable, they can create a forerunner effect that encourages other firms to develop their own reuse frameworks. Li, Li [34] suggest that government market regulation and the dissemination of relevant knowledge can significantly shape the behaviour of demolition and recycling enterprises, underscoring the importance of regulatory pressure and awareness-building in overcoming cultural resistance.

These findings reinforce that barriers to stakeholder engagement in CCWM are not isolated or purely technical but deeply embedded in economic incentives, governance structures, organizational cultures, institutional frameworks, and social dynamics. Therefore, targeted, stakeholder-specific interventions are needed rather than generic collaboration solutions. Addressing the high-frequency barriers, particularly unclear roles, regulatory uncertainty, misaligned priorities, and weak communication, represents a critical leverage point for strengthening collaboration and accelerating CCWM transitions.

Fig. 4 Mapping of CCWM collaboration/engagement barriers and the stakeholders influenced by and capable of influencing each barrier

Strategies for enhanced stakeholder engagement and collaboration

Table 5 presents the main strategies identified in the reviewed studies for enhancing stakeholder engagement and collaboration in CCWM. A recurring strategy in the reviewed studies is awareness, education and training of stakeholders to improve the understanding of CE strategies, benefits and skills for implementation [33, 106]. Targeted education programs for stakeholders could help address misconceptions, reduce resistance to change, and build confidence in recycled and reused concrete materials [67, 113]. For instance, clients/project owners and public/civil society actors require awareness programmes that explain the environmental, economic and lifecycle benefits of recycled and reused concrete materials. Consultants/design teams/professionals require training on circular design, material specification, technology application, risk assessment and performance evaluation. Contractors, manufacturers/suppliers and waste treatment companies require more practical

Table 5 Perceived strategies for effective stakeholder engagement and collaboration in CCWM

Code	Strategies	References
CS1	Awareness, education and training to build stakeholder capacity in circular practices.	She, Udawatta [113]; Adabre, Chan [67]; Mortensen and Kørnøv [85]; Vasconcelos, Silva [96]; Yu, Yazan [33]; Havinga, Mahdad [106].
CS2	Early stakeholder engagement and collaboration during project planning and design to align shared circular goals.	She, Udawatta [113]; Vasconcelos, Silva [96]; Köhler, Sönnichsen [98]; Ma and Hao [8]
CS3	Transparent communication and information sharing to support trust, coordination and information continuity across lifecycle stages.	She, Udawatta [113]; Yu, Yazan [33]; Harala, Alkki [28]; Köhler, Sönnichsen [98]; Ma and Hao [8].
CS4	Implement digital information sharing platform (e.g., BIM-based platforms) for real-time collaboration, tracking and decision making.	Adabre, Chan [67]; Liu, Teng [89]; Wang, Wu [95]; Vasconcelos, Silva [96]; Wang, Wu [95]; Yu, Yazan [33]; Mortensen and Kørnøv [85]; Havinga, Mahdad [106]; Harala, Alkki [28]; Ma and Hao [8].
CS5	Clearly defined roles, responsibilities, competencies, and accountability within project governance and contracts.	She, Udawatta [113]; Adabre, Chan [67]; Mortensen and Kørnøv [85]; Liu, Teng [89]; Ma, Tam [103].
CS6	Clearly defined regulations, standards and guidelines for compliance and quality assurance	She, Udawatta [113]; Adhi and Muslim [105]; Havinga, Mahdad [106].
CS7	Investment in demonstration projects to build stakeholders' confidence and skills.	Vasconcelos, Silva [96]; Ma and Hao [8]
CS8	Provision of economic incentives and funding to mitigate financial risks.	Adhi and Muslim [105]; Yu, Yazan [33]. Besklubova, Kravchenko [108].
CS9	Continuous monitoring, evaluation and reporting system to ensure accountability and improvement.	She, Udawatta [113]; Adhi and Muslim [105]; Ma, Tam [103].

training on sustainable construction and manufacturing practices, quality control, waste management, deconstruction and recovery planning.

Beyond awareness, the reviewed studies emphasize early stakeholder engagement and collaboration as a way of overcoming fragmentation and power imbalances [125]. Early involvement of consultants/designers, contractors, demolition actors, manufacturers/suppliers and waste treatment companies during project design and planning can support circular design, improve risk identification, strengthen material selection and enable planned reuse or recycling pathways [8]. For instance, manufacturers/suppliers and waste treatment enterprises that serve as producers and suppliers of reclaimed or recycled concrete products may provide upstream guidance on material acceptance criteria, recovery feasibility, processing capacity and quality requirements at the design stage.

Furthermore, transparent communication and effective information sharing are highlighted as essential for aligning stakeholder priorities, improving operational efficiency and building trust [28, 89]. CCWM depends heavily on shared responsibilities and timely information about component lifecycle history, material quality and quantity, location, recovery potential, technical requirements, cost implications and market demand. For example, contractors can provide feedback on construction or deconstruction feasibility and site-level constraints, while element manufacturers can also share technical information on material properties, testing procedures and condition assessment, which are necessary to verify the suitability of recovered components for reuse [30]. Therefore, structured communication through regular meetings, workshops and cross-stakeholder forums can help actors understand one another's perspectives and identify common ground [125]. Closely linked to this is the implementation of digital information-sharing platforms. Studies emphasise that the use of tools such as BIM-enabled databases and traceability tools can reduce information asymmetry while supporting documentation, material tracking and evidence-based decision-making [33, 95].

At the governance level, the reviewed studies also emphasise the importance of clearly defined roles, responsibilities, competencies and accountability for effective stakeholder engagement [67, 125]. When responsibilities for design, construction, deconstruction, material recovery, transport, testing and quality assurance are explicitly allocated, stakeholders are more likely to engage proactively and coordinate effectively [85]. In practical terms, this can be supported through circular procurement clauses, contractual requirements, and performance-based specifications that clearly assign obligations and accountability for circular practices across the project lifecycle [21, 74]. Implementing these structures would prevent weak engagement, undervalued expertise, project conflicts, and uncertainty over who should act at different lifecycle stages.

Moreover, robust regulatory frameworks and supportive policy instruments underpin many of these strategies. The literature shows that clearly defined regulations, standards and guidelines are required to provide institutional and technical certainty [105, 106]. Government/policymakers and industry associations play an important role in developing certification procedures, technical guidance, procurement rules and compliance requirements that make circular practices easier for project actors to adopt [30, 124]. In addition, investment in demonstration projects is another strategy identified in the literature to provide real-world settings for testing circular concrete products, deconstruction methods, reuse pathways, procurement models, digital tracking tools and collaboration routines [30]. These projects provide practical evidence on technical feasibility, cost implications, environmental benefits and implementation challenges [96, 132]. Consequently, this reduces perceived risk and builds market confidence among stakeholders. Ma and Hao [8] further emphasise that stronger regulatory enforcement can improve material standards and market platforms, compelling clients and contractors to move away from open-ended waste disposal towards closed-loop recycling.

The literature further identifies economic incentives and funding as necessary for addressing financial risks and high upfront costs that discourage stakeholder engagement in CCWM [108]. Government grants, subsidies, landfill levies, carbon-related incentives, tax reductions, and circular procurement can help offset costs and encourage participation, particularly for actors facing high capital expenses [33, 105]. However, the reviewed literature also suggests that, aside from government funding and incentives, public-private partnerships (PPPs) are essential to pool resources, share early-stage investment risks, and combine public policy support with private sector innovation and technical expertise strategies [8, 27].

Finally, continuous monitoring, evaluation, and reporting systems are essential to support transparency, accountability, and adaptive learning among project actors [113, 125]. This involves monitoring stakeholder engagement performance and CCWM outcomes; evaluating whether predefined targets (e.g., recovery rates) are met and whether shared responsibilities are fulfilled; and sharing performance information among all actors to ensure mutual accountability. Ultimately, these processes drive continuous improvement by identifying implementation gaps and providing feedback to refine circular frameworks and future engagement and collaboration strategies.

Taken together, the reviewed evidence suggests that strengthening stakeholder engagement in CCWM requires integrated mechanisms for capacity building, governance, economic incentives, digital support, and performance monitoring.

A conceptual framework for stakeholders' engagement, barriers and strategies for sustainable collaboration in CCWM

Building on the synthesis of stakeholder identification and roles across the project life cycle, the barriers constraining, and the strategies enhancing collaboration, this review proposes an integrated framework that conceptualises CCWM as a socio-technical system shaped by the interactions among actors, institutional conditions, and enabling mechanisms (see Fig. 5). At the core of the framework are the primary value-chain actors: Clients and project owners define strategic priorities and investment conditions; consultants and design teams translate these priorities into circular design and planning decisions; construction and demolition contractors operationalize material-efficient construction, deconstruction, and recovery; concrete manufacturers and suppliers provide circular products and logistics; waste treatment enterprises enable material recovery and value retention; and transportation and logistic enterprises maintain logistics efficiency and traceability. Surrounding this core are the enabling and institutional actors, such as government and policymakers, financial institutions, academic and research institutions, industry associations, and the general public and civil society, who shape the rules, incentives, knowledge base, standards, legitimacy, and infrastructure that determine whether circular pathways are feasible and trusted.

The framework further acknowledges that stakeholder collaboration is disrupted by multi-layered barriers that operate across economic, institutional, organizational, and social dimensions. To address these barriers, strategies such as awareness and capacity building, early engagement, transparent communication, digital information-sharing platforms, role clarification, regulatory support, financial incentives, demonstration projects, and continuous monitoring are positioned as targeted response mechanisms to mitigate them and support effective stakeholder engagement and collaboration. Conceptually, the framework illustrates that effective CCWM emerges when stakeholder engagement and collaboration, institutional conditions, and enabling strategies are mutually reinforcing, requiring a holistic, system approach.

The dynamics of this system often begin with institutional actors. Governments and policymakers' implementation of clear regulations, standards, guidelines, supervision, penalties and economic incentives can mitigate institutional and economic barriers by motivating contractors, manufacturers, and recyclers to improve waste management, product development and circular material practices. Financial institutions complement this process by reducing investment uncertainty through funding, preferential financing, and risk-sharing mechanisms, thereby supporting clients, manufacturers, and waste treatment companies in investing in circular concrete practices. Academic/research institutions help bridge knowledge gaps through education, capacity building, testing, and evidence generation, equipping consultants, contractors, manufacturers, and waste treatment companies with technical knowledge for circular design, material recovery, quality control, and technology

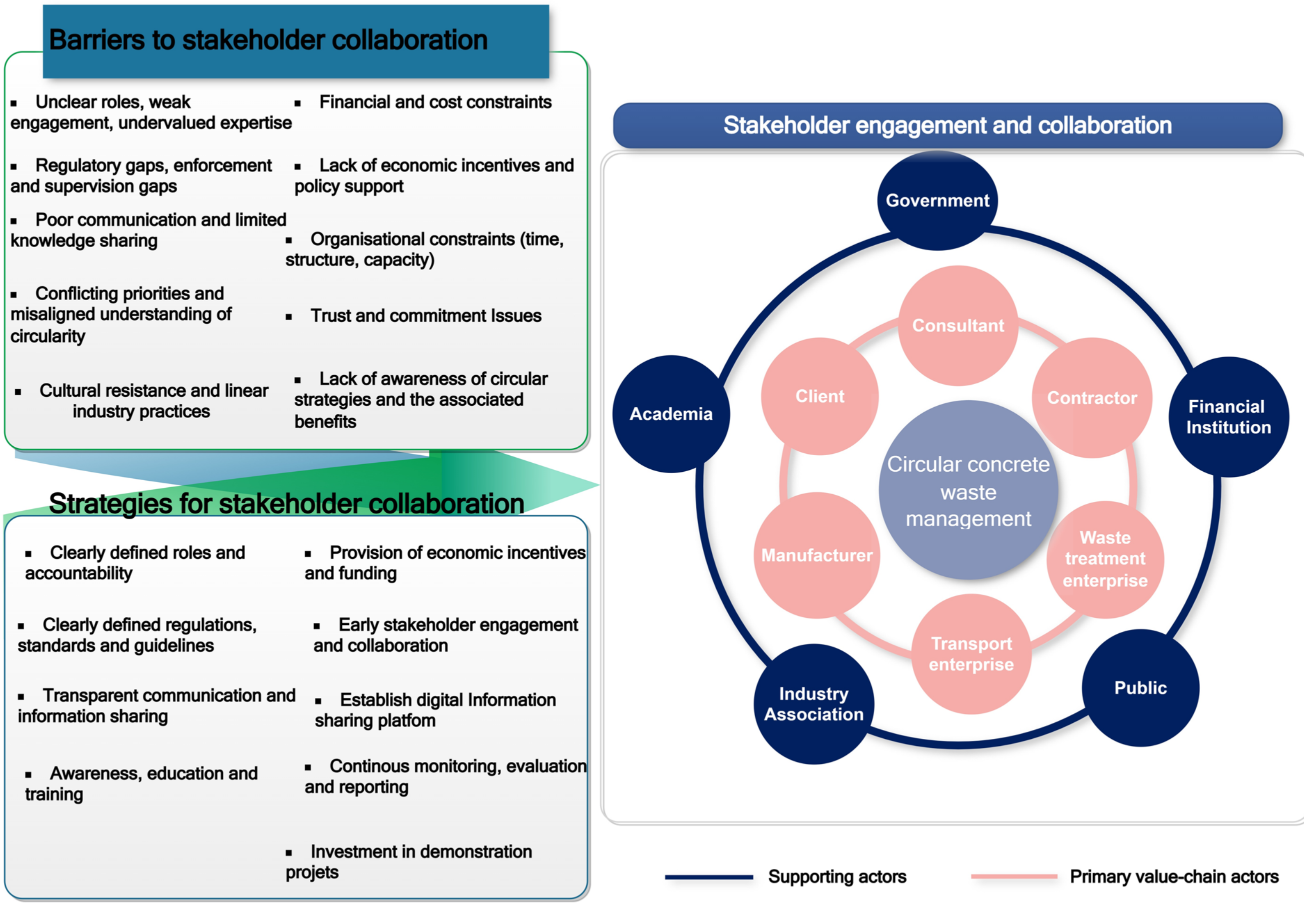

Fig. 5 A conceptual framework for stakeholder engagement and collaboration in CCWM

application. Industry associations can further strengthen the system by supporting professional guidance, standard-setting, knowledge exchange and trust-building across the sector. Public/civil society actors also contribute by shaping social acceptance, accountability and demand for more sustainable construction practices.

Once these enabling conditions are activated, a cascading loop emerges among the primary value-chain actors. The cycle begins with clients/project owners, whose commitment to circular procurement creates demand for circular concrete solutions. Through early stakeholder engagement, this demand enables consultants/design teams to prioritise design-for-deconstruction, specify recycled concrete aggregates and incorporate reuse, repair, refurbishment or recovery considerations into project designs. These design decisions then shape the actions of contractors and demolition/deconstruction actors, who then shift from conventional demolition towards selective deconstruction, improved sorting, site-level documentation and better waste management. Consequently, high-quality sorting enables waste treatment companies to produce cleaner, less contaminated waste, improving the production of recycled concrete aggregates and other recoverable concrete materials. Manufacturers/suppliers can then use these inputs to produce reliable circular concrete products, which are supplied to new projects and used by contractors to meet client demand. In this way, the framework illustrates a reinforcing circular pathway in which stakeholder roles, engagement, and collaboration support concrete material loop closure.

Furthermore, the framework implies feedback effects over time. When regulations and standards are clear, economic support is available, stakeholder capacity is strengthened, roles are well defined, and key actors are engaged early, information sharing improves, trust increases, and actors become more willing to invest in circular procurement, deconstruction, recovery and recycled-product supply. This can create a reinforcing pathway in which successful CCWM implementation builds confidence and encourages wider adoption. Conversely, weak regulations, unclear standards, limited economic support, inadequate capacity, ambiguous roles, poor communication and weak documentation can reduce trust, suppress demand for recovered materials and discourage investment by manufacturers and waste treatment companies, thereby reinforcing linear disposal practices.

Ultimately, the conceptual framework provides a structured lens for analysing “who acts” as stakeholders, “what constrains action” as barriers and “what enables change” as strategies in CCWM. By moving beyond fragmented stakeholder or CE strategy-specific analyses, the study offers a lifecycle-oriented understanding of how collaboration can be strengthened across the concrete value chain. Future empirical research can operationalise this framework through causal loop diagramming, stakeholder surveys, social network analysis or longitudinal case analysis to examine how the identified barriers and strategies, individually or collectively, influence stakeholder engagement, collaboration quality and CCWM implementation. For policy design and industry application, the framework can serve as a systems-thinking roadmap for identifying the stakeholders involved in CCWM, the causes of coordination failures, the actors most affected, the actors with leverage to intervene and the strategies needed to strengthen collaboration. It also shows that CCWM implementation depends on both value-chain and supporting actors’ capability, while value-chain transformation depends on government/policymakers, financial institutions, academic/research institutions, industry associations and public/civil society.

Conclusions

This study advances the understanding of CCWM by moving beyond the identification of technical challenges to examine the collaboration and engagement dynamics that shape it across the construction project life cycle, rather than relying on generic construction and demolition waste frameworks. Through a systematic review, the eleven stakeholder groups were identified, and a RACI-based governance framework was applied to present how responsibilities, accountability, consultation, and information roles are distributed from design through end-of-life. Across the literature, various stakeholders, including clients/project owners, consultants and design teams, construction and demolition contractors, manufacturers/suppliers, transportation and logistics actors, recycling and waste-treatment enterprises, regulators and municipalities, financial institutions, research and education bodies, industry associations, and public and civil society actors, each hold distinct responsibilities that collectively determine whether circular strategies, reduction, reuse, repair/refurbishment, and high-value recycling, can be implemented at scale. However, the RACI analysis reveals persistent coordination gaps in accountability, early contractor involvement, traceability and sustainability performance assessment.

The findings further show that stakeholder collaboration remains constrained by recurring barriers, notably unclear roles and decision rights, weak early engagement, and the undervaluation of practice-based expertise, alongside regulatory gaps and complexity, misaligned priorities, and poor communication and information exchange. Strengthening collaboration, therefore, requires early and inclusive stakeholder engagement, clearer allocation of roles and accountability, harmonized standards for reused and recycled concrete, digital information-sharing platforms, training and capacity building, demonstration projects, and financing instruments that de-risk circular technologies and recovery infrastructure.

By mapping collaboration barriers to both affected stakeholders and those with leverage to address them, this study demonstrates that engagement challenges in CCWM are relational rather than uniform, varying by stakeholders’ positions in the value chain.

These insights are sythensized into an integrated conceptual framework linking stakeholders, cross-cutting collaboration barriers, and targeted pragmatic strategies within a single structure and provide a practical, clear lens for diagnosing coordination failures and prioritizing interventions, constituting a strong base for future empirical research, policy design, and practice-oriented implementation of CCWM.

Furthermore, this study has some limitations. The literature synthesis was restricted to English-language publications indexed in Scopus and Web of Science, which may have excluded relevant studies published in other databases or languages. Future reviews could expand coverage by combining multiple databases. Also, many of the reviewed studies are context-specific, limiting comparability across regulatory and market settings and constraining robust generalization of findings. Lastly, the conceptual framework and the mapping outputs developed is based on secondary evidence and requires empirical validation to confirm their practical applicability.

Future research directions

Future research should emperically test and validate the conceptual framework and mapping outputs developed in this study across different regulatory, market and infrastructural contexts, particularly in developing economies. More focused studies are also required on underrepresented stakeholder groups, especially financial institutions, academic and research institutions, and the public. Studies should also develop measurable performance indicators for stakeholder engagement quality and connect them to circular outcomes such as recovery rates, material quality, cost viability, and embodied-carbon reductions. Finally, future research should explore how digital tools can strengthen coordination gaps and improve information sharing in CCWM implementation.

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