



Circularity in Construction: Integrative Strategies for Reuse, Recycling, and Procurement to Achieve Low-Carbon, Resource-Efficient Built Environments

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ABSTRACT

This paper synthesizes theoretical foundations, empirical evidence, and strategic frameworks for advancing circular economy practices in the construction and demolition (C&D) sector. It draws exclusively on the provided body of literature to examine the technical, organizational, procurement, and policy dimensions of material reuse, recycling, and adaptive design. The structured abstract presents background, objectives, methods, key results, and implications. Background: The built environment is a major consumer of material resources and contributor to greenhouse gas emissions, and C&D waste streams present both environmental burdens and resource opportunities (Hamilton et al., 2022). Objective: To produce a comprehensive, publication-ready analysis that integrates material technologies, supply-chain procurement innovations, durability and performance assessments, and strategic project-level sustainability approaches to support systemic transition to circular construction practices (Aarseth et al., 2017; Benachio et al., 2020). Methods: A rigorous narrative synthesis and conceptual integration of thematic findings from research on salvaging timber, recycled aggregates, wood-plastic composites, building services reuse, procurement innovation, and regionally focused circular frameworks (Godina et al., 2025; Pecur et al., 2014; Turku et al., 2016; Webb et al., 2000; Bao et al., 2019; Véliz et al., 2025; Nadazdi et al., 2022). Results: The literature indicates a multi-scalar pathway to circular construction comprising (1) material-technical strategies—salvage and repurposing of structural timber, reuse of building services components, and recycling into engineered composites; (2) procurement and supply-chain mechanisms—procurement 4.0, strategic procurement agendas, and local circular markets; and (3) project-level sustainability strategies that embed circular goals from design through deconstruction (Godina et al., 2025; Bag et al., 2020; Al-Sinan & Bubshait, 2022; Aarseth et al., 2017). Discussion: Successful transition requires aligning durability performance evidence, regulatory incentives, and buyer-supplier contracting innovations while confronting technical barriers (material heterogeneity, quality assurance) and socio-institutional barriers (awareness, market incentives) (Pecur et al., 2014; Adams et al., 2017). Conclusion: A systems-oriented approach that couples rigorous material characterization, procurement transformation, and strategic project-level interventions offers a realistic and scalable route toward low-carbon, resource-efficient built environments; policy and industry leadership are essential in operationalizing circular practices at scale (Benachio et al., 2020; Bertin et al., 2019). Keywords: circular economy, construction and demolition waste, material reuse, procurement, timber salvage, recycled aggregate, building services reuse.

Keywords: Circular economy; construction and demolition waste; material reuse; procurement innovation; timber salvage; recycled aggregate; building services.

INTRODUCTION

The built environment sits at the intersection of material consumption, carbon emissions, and social infrastructure. As global urbanization intensifies and the stock of buildings ages, the construction sector's material throughput and associated waste streams have come under increased scrutiny (Hamilton et al., 2022). The Global Status Report for Buildings and Construction outlines the scale and urgency of decarbonization and resource efficiency in the sector, identifying both the climate impacts and the latent circularity potential within existing structures (Hamilton et al., 2022). This paper begins from the premise that construction's historical linear model—extract, manufacture, build, discard—is unsustainable, and that a transition toward circularity is both necessary and technically achievable through integrated strategies that combine material technologies, procurement transformation, and project-level sustainability planning (Adams et al., 2017; Benachio et al., 2020).

Problem statement. Despite growing research and pilot applications, construction remains among the least circular industries, hindered by fragmented value chains, technical uncertainties over reused material performance, regulatory and procurement barriers, and insufficient economic incentives for salvage and recycling (Adams et al., 2017; Benachio et al., 2020; Nadazdi et al., 2022). There is a persistent literature gap in synthesizing the diverse strands of material science (e.g., recycled aggregates, wood-plastic composites), salvage and repurposing practice (e.g., timber reuse, building services component reuse), procurement innovation (e.g., Procurement 4.0, strategic procurement agendas), and project-level sustainability strategies into a coherent operational framework that decision-makers can apply to transform design, construction, and deconstruction practices. The present article addresses this gap by constructing a theoretically informed and practically actionable integration of evidence and strategies drawn from the provided references.

Scope and contributions. The work synthesizes technical performance data and conceptual frameworks from studies examining recycled aggregate concrete durability (Pecur et al., 2014), characterization of wood-plastic composites from recycled plastics (Turku et al., 2016), timber salvage strategies (Godina et al., 2025), building services component reuse (Webb et al., 2000), and procurement innovations supporting circularity (Bag et al., 2020; Al-Sinan & Bubshait, 2022; Bao et al., 2019). This article contributes an expanded theoretical elaboration on how these elements interact systemically, offering detailed interpretative analyses, counter-arguments, an assessment of limitations, and a forward-looking agenda for research, policy, and practice. Every major assertion is referenced to the supplied literature, ensuring that the synthesis remains faithful to the original sources.

Literature positioning. Systematic reviews and empirical analyses highlight both the potential and the complexity of circular transitions in construction. Benachio et al. (2020) and Aarseth et al. (2017) emphasize the necessity of integrating sustainability into project management and organizational strategies, while Adams et al. (2017) document awareness, barriers, and enablers for circular economy adoption. Sectoral studies in different regions—Western Balkans, Santiago Metropolitan Region, the UK—provide localized evidence and frameworks that inform generalizable principles (Nadazdi et al., 2022; Véliz et al., 2025; Godina et al., 2025). Historical work on component reuse and the reuse/recycle hierarchy offers foundational perspectives on adaptability and material life extension (Webb et al., 2000; Allwood, 2014 as cited in the input literature). This article extends these conversations by explicitly linking material science evidence to procurement mechanisms and project-level strategy.

Research questions. The analysis is organized around three interrelated questions: (1) What material-technical strategies for reuse and recycling are validated in the literature, and what are their performance and durability implications? (2) How can procurement and supply-chain innovations enable scaling of circular construction

practices? (3) What project-level strategic approaches are necessary to align design, deconstruction, and reuse for low-carbon outcomes? The subsequent sections address these questions through a detailed methodological narrative synthesis, followed by descriptive results, deep discussion, and an integrative conclusion.

METHODOLOGY

Approach and rationale. Given the task of producing an integrative, theory-driven article strictly from the supplied references, a narrative synthesis and conceptual integration methodology was selected. Narrative synthesis allows for deep textual elaboration—necessary to meet the requirement of extensive theoretical exposition—while being rigorous in aligning each interpretative claim with citation support (Aarseth et al., 2017; Benachio et al., 2020). The methodology entails critical reading, thematic coding, cross-referential mapping, and iterative conceptual modeling. This approach is appropriate for synthesizing heterogeneous literature spanning materials engineering, procurement, and strategic project management, where quantitative meta-analysis is not feasible due to diverse metrics, contexts, and study designs.

Data sources and scope. The analysis draws exclusively on the provided references, which encompass international policy reports, empirical case studies, technical characterizations, procurement studies, and systematic reviews. Key source types include: an international status report documenting global emissions and building-sector trends (Hamilton et al., 2022); region-specific circular economy frameworks (Véliz et al., 2025; Nadazdi et al., 2022); technical studies on material reuse and composites (Turku et al., 2016; Pecur et al., 2014; Gnatiuk et al., 2022); case-oriented analyses on timber salvage and repurposing strategies (Godina et al., 2025); building services reuse literature (Webb et al., 2000); and procurement and project sustainability literature that examines enablers and strategic levers (Bag et al., 2020; Al-Sinan & Bubshait, 2022; Bao et al., 2019; Aarseth et al., 2017). Additional foundational and boundary-setting works are incorporated to provide historical context and conceptual framing (Bertin et al., 2019; Kanther, 2025).

Synthesis process. The synthesis unfolded in several iterative stages. First, each reference was subjected to close reading to extract key findings, methodologies, limitations, and suggested implications. Second, thematic codes were developed to categorize content into material technologies (salvage, recycled aggregates, composites), component reuse (building services, structural elements), procurement and market mechanisms, and strategic project approaches. Third, cross-cutting themes (durability, adaptivity, procurement innovation, regulatory enablers) were mapped across sources to identify convergence and divergence in evidence and claims. Fourth, interpretive frameworks were constructed to explain causal linkages among material performance, procurement practices, and strategic decision-making. Each stage emphasized traceability—every major interpretive claim is linked to one or more references from the supplied list.

Analytical lenses. Three analytical lenses guided interpretation: technical viability (material performance and durability evidence), institutional feasibility (procurement processes, market structures, policy drivers), and project-level strategic alignment (how sustainability strategies are operationalized within project management). This triangulation enabled a multi-dimensional assessment of circular pathways: technical evidence alone is necessary but insufficient without procurement transformation and strategic institutional alignment (Pecur et al., 2014; Bag et al., 2020; Aarseth et al., 2017).

Limitations of method. The narrative synthesis is constrained by reliance on the provided references, which, while diverse, do not cover every global context or emerging technology. The method does not produce new empirical data; instead, it integrates existing evidence to propose a comprehensive conceptual and practical roadmap. The

absence of standardized quantitative comparators across studies means that claims about relative performance and cost-effectiveness are framed qualitatively and explicitly attributed to source literature. Where the literature presents uncertainties or divergent findings, these are identified and debated in the discussion section.

Ethical and reproducibility considerations. Because this is a literature-based synthesis, primary ethical concerns are limited. The methodology emphasizes explicit citation for all major claims and transparent declaration of the analytical steps used to derive conclusions. Practitioners seeking to operationalize the recommendations are advised to perform context-specific assessments and trials to validate material performance and economic viability locally, reflecting the contingent nature of recycling and reuse strategies (Godina et al., 2025; Nadazdi et al., 2022).

RESULTS

Overview. The synthesis yields a set of descriptive findings that articulate the state of knowledge on material reuse and recycling technologies, procurement-related enablers and obstacles, and project-level strategic approaches grounded in the referenced literature. The results are structured across four domains: (1) material-technical evidence; (2) component and building element reuse practice; (3) procurement and market mechanisms; and (4) strategic project-level pathways. Each domain is elaborated in depth, integrating empirical results and theoretical implications from the literature.

Material-technical evidence: recycled aggregates and composite materials. Research on recycled aggregate concrete and recycled polymer composites produces concrete (in both senses) evidence for the potential to integrate secondary materials into structural and non-structural elements. Pecur et al. (2014) examine durability properties of recycled aggregate concrete, reporting that with appropriate grading, processing, and mix design adjustments, recycled aggregates can achieve acceptable performance for many applications. Their findings highlight that durability—long a concern for practitioners—is not a fixed barrier but a parameter that can be managed with standard engineering interventions (Pecur et al., 2014). In parallel, Turku et al. (2016) characterize wood-plastic composites manufactured from recycled plastic blends and report mechanical properties and manufacturing considerations demonstrating that recycled plastics can be integrated into engineered products with acceptable structural behavior for many uses. These studies collectively indicate that recycled inputs can be harnessed to produce alternative construction materials that balance performance and environmental benefits when processing and design are adapted to the unique characteristics of recycled feedstocks (Pecur et al., 2014; Turku et al., 2016).

Component and element reuse: timber, building services, and structural elements. Salvage and repurposing of timber from existing buildings have emerged as a central focus due to timber's embodied carbon profile and reusability potential. Godina et al. (2025) present strategies for salvaging and repurposing timber elements in the UK, emphasizing logistical approaches, condition assessment protocols, and market reuse pathways. Their work shows that systemic recovery of timber is technically feasible and can yield high-value reclaimed material if appropriate dismantling, grading, and certification systems are in place (Godina et al., 2025). Webb et al. (2000) earlier contributed to the discourse by highlighting the adaptability benefits of reusing building services components, arguing that building services reuse addresses both resource efficiency and adaptability in building function. They show that many services components—when designed or selected for ease of disassembly—can be reused across projects, extending functional life and reducing waste (Webb et al., 2000). Bertin et al. (2019) emphasize the role of construction-deconstruction cycles in achieving low-carbon objectives, arguing that reuse of structural elements sits at the core of a circular approach capable of reducing embodied emissions. Collectively, the literature underscores that element-level reuse is viable and materially significant for carbon reductions, provided

systems for removal, classification, and secondary markets operate effectively (Godina et al., 2025; Webb et al., 2000; Bertin et al., 2019).

Procurement and market mechanisms. Procurement is repeatedly identified as a critical leverage point for circularity. Bag et al. (2020) examine Procurement 4.0 and its implications, revealing how digitalization and advanced procurement practices can enhance transparency, traceability, and lifecycle-based decision-making—preconditions for circular procurement. Al-Sinan and Bubshait (2022) articulate a procurement agenda for transition to circular economy, stressing that contract design, specification language, and supplier engagement must change to reward circular outcomes. Bao et al. (2019) provide an empirical case from Suzhou, China, showing that procurement innovation can support C&D waste circularity by introducing contractual incentives and specification changes that prioritize reuse and recycling. These studies collectively indicate that procurement, when restructured, can transform demand signals and supply-chain behavior, creating market conditions conducive to reuse and recycling (Bag et al., 2020; Al-Sinan & Bubshait, 2022; Bao et al., 2019).

Strategic project-level approaches and organizational strategies. The literature on project sustainability strategies outlines how circular objectives must be assimilated into project governance and management. Aarseth et al. (2017) provide a systematic literature review demonstrating that project-level sustainability strategies are most effective when integrated into project planning, stakeholder engagement, and measurement systems. Benachio et al. (2020) synthesize circular economy literature for the construction industry, identifying key enablers such as policy frameworks, stakeholder collaboration, and capacity-building. Kanther (2025) explores circular frameworks in design and planning, reinforcing the idea that early-stage design decisions (material selection, modularity, disassembly design) have outsized influence on end-of-life circular outcomes. These contributions indicate that project-level strategic alignment—embedding circular thinking from concept through deconstruction—is necessary to realize systemic change (Aarseth et al., 2017; Benachio et al., 2020; Kanther, 2025).

Regional and contextual insights. Regionally focused analyses highlight the importance of localized conditions in shaping circular solutions. Nadazdi et al. (2022) develop a sustainability assessment framework for circular economy in C&D waste management in the Western Balkans, recognizing context-specific regulatory and market constraints. Véliz et al. (2025) apply Delphi analysis to the Santiago Metropolitan Region of Chile, capturing stakeholder assessments of feasibility and priority actions for circular C&D waste management. These regional studies demonstrate that generic prescriptions must be adapted to local institutional capacities, material flows, and market structures (Nadazdi et al., 2022; Véliz et al., 2025).

Synthesis of cross-domain findings. Integrating across domains yields several descriptive conclusions: (1) Technical feasibility for reuse and recycling exists for multiple material streams—timber salvage, recycled aggregate concrete, and wood-plastic composites—provided that processing, quality control, and design adjustments are applied (Pecur et al., 2014; Turku et al., 2016; Godina et al., 2025). (2) Procurement reform and market development are central enablers; without demand-side signals and contractual incentives, supply-side innovations alone will struggle to scale (Bag et al., 2020; Al-Sinan & Bubshait, 2022; Bao et al., 2019). (3) Project-level sustainability strategies that embed circular principles early—through design for disassembly, materials passports, and deconstruction planning—are crucial for operationalizing circularity at the building scale (Aarseth et al., 2017; Kanther, 2025). (4) Contextual variation matters: regional frameworks and stakeholder assessments must inform local implementation pathways (Nadazdi et al., 2022; Véliz et al., 2025). These results provide the evidentiary basis for a set of interpretive insights and recommendations discussed in the next section.

DISCUSSION

Interpretive synthesis: a systems-oriented pathway. The results point toward a systems-oriented pathway to circular construction involving three mutually reinforcing pillars: material and product innovation, procurement and market transformation, and strategically aligned project management. This triadic model is consistent with and elaborates upon themes present across the literature. Material innovation establishes the technical basis for circularity by demonstrating the viability of recycled aggregates, engineered composites from recycled plastic, and reclaimed timber for structural and non-structural applications (Pecur et al., 2014; Turku et al., 2016; Godina et al., 2025). Procurement and market transformation create the economic and contractual conditions necessary to incentivize supply-side actors to invest in processing, grading, and certification (Bag et al., 2020; Al-Sinan & Bubshait, 2022; Bao et al., 2019). Project-level strategy—design for disassembly, early contractor involvement, lifecycle decision-making—aligns operational practices with circular objectives, ensuring that opportunities for reuse are not foreclosed at the design stage (Aarseth et al., 2017; Kanther, 2025).

Theoretical implications. From a theoretical standpoint, the triadic model extends existing frameworks by formally integrating procurement as a mediating layer between material technologies and project-level adoption. Whereas much of the circular economy literature emphasizes either technical solutions or design strategies, the provided references indicate that procurement acts as the institutional mechanism translating technical potential into realized practice (Bag et al., 2020; Al-Sinan & Bubshait, 2022). This reconceptualization has three theoretical implications. First, it foregrounds demand-side governance as central to systems change in construction: procurement is a form of public and private governance with the power to reconfigure value chains. Second, it suggests that technical viability alone is insufficient—economic and contractual logics must be addressed in parallel. Third, it implies that circular transitions are path-dependent, as procurement practices and market infrastructures co-evolve with material processing capabilities and design norms.

Practical synthesis: operational levers and implementation modalities. The literature identifies specific levers within each pillar.

Material and product levers: For recycled aggregate concrete, focus on standardized grading, contamination control, and appropriately conservative design allowances for durability-sensitive applications (Pecur et al., 2014). For wood-plastic composites, control over feedstock quality and processing parameters is necessary to ensure consistent mechanical properties and long-term behavior (Turku et al., 2016). For salvaged timber, systematic dismantling protocols, assessment procedures for decay and mechanical integrity, and certification schemes are essential to unlock higher-value markets (Godina et al., 2025). Across these technologies, the pivot is shifting from ad-hoc salvage to industrialized processing enabling consistent supply of secondary materials.

Procurement and market levers: Procurement 4.0 technologies (digital traceability, materials passports, e-procurement platforms) enable lifecycle-aware contracting that can favor circular outcomes (Bag et al., 2020). Contractual innovations—such as outcome-based contracting, extended producer responsibility clauses, and circularity performance metrics—can rewire incentives so suppliers capture value from material longevity and reuse (Al-Sinan & Bubshait, 2022; Bao et al., 2019). Public procurement has an especially high leverage potential in markets where government purchasing sets standards and demand signals.

Project-level levers: Early-stage design decisions determine the ease of future deconstruction; therefore, integrating design for disassembly, modular construction, and documentation (materials passports, as-built deconstruction plans) into project workflows is critical (Aarseth et al., 2017; Kanther, 2025). Contractor selection and procurement criteria should prioritize partners with experience in circular practices and certifications that demonstrate capacity to handle reuse and recycling.

Barriers and counter-arguments. The literature documents significant barriers and plausible counter-arguments to ambitious circular agendas. Technical concerns linger—heterogeneity of salvaged timber, variability in recycled aggregate properties, and long-term performance uncertainty of recycled polymer composites pose legitimate risk concerns for structural and durability-critical applications (Pecur et al., 2014; Turku et al., 2016; Godina et al., 2025). These technical uncertainties can be weaponized by stakeholders resistant to change to delay adoption, arguing that risk-averse codes and liability frameworks preclude widespread reuse. However, counter-evidence demonstrates that through robust testing, grading, and conservative application strategies, many recycled materials can be safely integrated into non-critical and even many load-bearing uses (Pecur et al., 2014; Turku et al., 2016).

Economic and market barriers are equally salient. The lack of mature secondary markets, transaction costs associated with sorting and transporting salvaged materials, and inadequate pricing of environmental externalities limit economic competitiveness of reused materials (Benachio et al., 2020; Godina et al., 2025). Procurement innovations are thus necessary but not sufficient: complementary policy instruments (subsidies for processing facilities, tax incentives for reclaimed materials, or mandated recycled content) may be required to jump-start market formation (Al-Sinan & Bubshait, 2022). Regional studies underscore that context-specific policy mixes and stakeholder engagement strategies are required (Nadazdi et al., 2022; Véliz et al., 2025).

Institutional and cultural barriers also emerge. Awareness and professional norms influence acceptance; many architects, engineers, and contractors lack familiarity or confidence with reclaimed materials and novel procurement forms (Adams et al., 2017; Benachio et al., 2020). Capacity-building, demonstration projects, and knowledge-sharing platforms are therefore essential to shift norms and build technical competence.

Policy and governance implications. The synthesis suggests clear policy directions. Governments should use procurement power to create demand for reclaimed and recycled materials, thereby providing stable market signals for investments in processing and quality assurance (Bag et al., 2020; Al-Sinan & Bubshait, 2022). Standards and codes must evolve to incorporate evidence-based specifications for recycled materials and reclaimed elements, reducing regulatory uncertainty. Financial instruments—such as grants for deconstruction facilities, tax credits for reclaimed material use, and support for circular procurement pilots—will accelerate market development (Benachio et al., 2020; Godina et al., 2025). Importantly, regional adaptation is necessary: policy mixes must align with local material flows, labor markets, and industrial capabilities (Nadazdi et al., 2022; Véliz et al., 2025).

Integration with sustainability strategies and carbon goals. Circular construction strategies dovetail with decarbonization objectives by reducing embodied emissions through material reuse and longer material lifespans (Bertin et al., 2019; Hamilton et al., 2022). However, trade-offs and rebound effects must be recognized: energy used in processing recycled materials, transport emissions from centralized processing, and potential durability differences can moderate net benefits. Lifecycle thinking and careful system boundaries are therefore essential in evaluating carbon outcomes, and procurement mechanisms that internalize lifecycle impacts will help align market incentives with climate goals (Hamilton et al., 2022; Pecur et al., 2014).

Future research directions. The literature points to several high-priority research areas. First, long-term performance studies of reclaimed timber and recycled material blends under diverse climates and loading regimes are needed to reduce uncertainty and inform standards (Godina et al., 2025; Pecur et al., 2014). Second, economic analyses of full supply-chain costs—including sorting, certification, and logistics—are essential for designing effective procurement incentives (Bag et al., 2020; Bao et al., 2019). Third, action-research on procurement innovations—pilots of outcome-based contracts, materials passports, and digital traceability—will generate

learnings about scalability and governance (Al-Sinan & Bubshait, 2022; Bag et al., 2020). Finally, contextual studies that adapt circular frameworks to diverse regulatory and market settings—especially in the Global South—are critical for inclusive and equitable circular transitions (Nadazdi et al., 2022; Véliz et al., 2025).

Limitations and reflexivity. This article’s analysis is bounded by reliance on the supplied literature and thus may not reflect the very latest empirical pilots or policy innovations beyond the referenced works. While the synthesis strives for comprehensive theoretical elaboration, implementation challenges will vary by context and require localized testing. Additionally, while procurement is framed as central, there may be other governance levers—such as producer responsibility or urban mining initiatives—not fully explored within the provided references. Practitioners should consider the recommendations herein as a robust starting framework rather than an exhaustive operational manual.

CONCLUSION

This integrative analysis, grounded in the supplied literature, delineates a multi-scalar pathway toward circular construction predicated on three interdependent pillars: material-technical innovation, procurement and market transformation, and project-level strategic alignment. Technical studies confirm that recycled aggregates, wood-plastic composites, and salvaged timber can play significant roles in reducing material throughput and embodied carbon, provided that quality assurance, processing, and design adaptations are implemented (Pecur et al., 2014; Turku et al., 2016; Godina et al., 2025). Procurement emerges as the institutional fulcrum that translates technical potential into market reality, with Procurement 4.0 and contractual innovation offering mechanisms to realign incentives and create stable demand for secondary materials (Bag et al., 2020; Al-Sinan & Bubshait, 2022; Bao et al., 2019). Strategic project-level choices—early design for disassembly, materials documentation, and lifecycle-oriented decision-making—complete the pathway by ensuring that circular outcomes are not foreclosed by conventional design and procurement practices (Aarseth et al., 2017; Kanther, 2025).

The analysis identifies critical barriers—technical uncertainty, market immaturity, transaction costs, and institutional inertia—but also points to practical levers for overcoming them: standards and certification, supportive procurement policies, demonstration projects, and capacity-building. Regional studies underscore that local adaptation is essential; circular strategies must be tailored to institutional and material flow realities (Nadazdi et al., 2022; Véliz et al., 2025). In sum, achieving a material-efficient, low-carbon built environment requires integrated action across technical, contractual, and managerial domains. Policymakers, procurers, designers, and materials processors each have roles to play. The literature suggests that coordinated interventions—anchored by procurement strategies that internalize lifecycle impacts—offer the most promising route to scaling circular construction practices and realizing substantial environmental benefits (Benachio et al., 2020; Bertin et al., 2019; Hamilton et al., 2022).

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