



Advancing Circularity In Construction: Integrating Material Reuse, Recycling, And Sustainable Procurement For The Built Environment

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Abstract: The construction sector is a major consumer of raw materials and a significant generator of waste. Transitioning from linear to circular material flows in construction requires integrated approaches encompassing material science, waste processing technologies, procurement strategies, and policy and organizational mechanisms. This paper synthesizes evidence from technical studies on recycling and reuse of construction materials, case studies on deconstruction practices, life-cycle perspectives, material flow analysis, and procurement and management literature to present a unified theoretical and practical framework for circular construction. The manuscript critically examines recycled concrete and masonry aggregates, alternative thermal insulation from textile wastes, wood–plastic composites with secondary materials, and systemic reuse of building elements. It further explores the role of procurement and project delivery methods in enabling circular outcomes, identifying barriers, drivers and stakeholder interactions. Methodologically, the research integrates a rigorous literature synthesis, comparative conceptual modelling, and a reasoned normative framework that maps technical potential to procurement strategies and organizational processes. Results show that while recycled aggregates and alternative insulation materials can meet many technical performance parameters, their adoption is conditioned by quality assurance mechanisms, regulatory clarity, and procurement incentives. Sustainable procurement models — particularly collaborative and integrated procurement practices — significantly improve reuse outcomes by aligning incentives, fostering trust and enabling whole-life cost assessments. The discussion elaborates on theoretical implications for industrial ecology in construction, critiques existing lifecycle assessment approaches, and offers detailed recommendations for

policy, practice and research. Limitations include reliance on secondary literature and heterogeneity in empirical studies; future research should deploy multi-scalar empirical trials combining material testing with procurement pilots. The paper concludes with a comprehensive, actionable roadmap to accelerate circular construction that bridges technical feasibility and organizational adoption through targeted policy, procurement reform, and cross-sectoral collaboration.

Keywords: Circular construction, recycled aggregates, reuse potential, sustainable procurement, material flows, life-cycle assessment.

Introduction: The imperative to transform the construction sector toward sustainable, low-impact, and resource-efficient models is widely acknowledged across academic, industrial and policy communities. The built environment consumes vast quantities of virgin materials, and construction and demolition (C&D) activities generate substantial waste streams that, under linear paradigms, are accumulated in landfills or used in low-value applications (Purnell & Dunster, 2010; De Venny, 1999). This situation presents both an environmental problem and an economic opportunity: by rethinking materials and processes, the sector can dramatically reduce embodied impacts, recover value from end-of-life assets, and reduce demand for virgin resources (Joseph & Tretsiakova-McNally, 2010; Briga-Sá et al., 2013).

Scholars and practitioners have proposed many pathways for circularity, including the reuse of building elements and components, recycling of concrete and masonry to produce secondary aggregates, substitution of conventional insulation with textile waste, and incorporation of waste streams into wood-plastic composites (Durmisevic et al., 2017; Purnell & Dunster, 2010; Briga-Sá et al., 2013; Keskisaari & Kärki, 2018). Each technical pathway has unique material, structural, performance and regulatory challenges, but these technical considerations are inseparable from organizational and procurement structures that govern how projects are delivered and how materials are specified and purchased (Eriksson & Westerberg, 2011; El-Sayegh, 2008; Elhag, Eapen & Ballal, 2019). Without aligning procurement incentives, contracts, and trust relationships among stakeholders, even technically feasible circular solutions often remain marginal (Guy, 2006; Hobbs & Adams, 2017).

Despite growing research into discrete technical solutions and policy experiments, major literature gaps remain. First, many technical studies report material

performance under controlled conditions but lack systematic integration with procurement and lifecycle cost frameworks that reflect real-world decision contexts (Bojan et al., 2018; Purnell & Dunster, 2010). Second, the reuse of building elements requires systemic assessment tools to evaluate candidate elements' reuse potential across waste typologies, building systems and market contexts; while frameworks exist, they require refinement and operationalization (Durmisevic et al., 2017). Third, research on the influence of procurement models on circular outcomes is expanding, yet there is not yet a consolidated, actionable linkage between procurement mechanisms, contractual instruments and measurable circularity results (Eriksson & Laan, 2007; Eriksson & Westerberg, 2011; Ershadi et al., 2021). Finally, comparative life-cycle assessments (LCAs) of recycled materials have produced mixed conclusions due to differences in system boundaries, data quality and assumptions; reconciling these findings to inform procurement decisions remains challenging (Buyle et al., 2013; Bribián, Capilla & Usón, 2011).

This article addresses these gaps by synthesizing cross-disciplinary evidence and constructing a comprehensive framework that aligns technical viability of recycled and reused materials with procurement strategies and organizational mechanisms necessary for scaling circular construction. The contributions are threefold. First, it provides an exhaustive technical synthesis of recycled concrete, masonry rubble reuse, textile-based insulation, and composite products incorporating waste streams, assessing performance, processing requirements, and environmental implications (Purnell & Dunster, 2010; De Venny, 1999; Briga-Sá et al., 2013; Keskisaari & Kärki, 2018). Second, it integrates procurement and project delivery literature to articulate how procurement choices influence circular outcomes, highlighting collaborative procurement, project management office roles, and dispute moderation as essential enablers (Elhag, Eapen & Ballal, 2019; Ershadi et al., 2021; Eriksson & Westerberg, 2011). Third, the paper offers a normative, actionable roadmap linking material-level decisions to organizational procurement interventions that collectively optimize environmental and economic outcomes while respecting regulatory constraints (Ghaffar, Burman & Braimah, 2020; Guerra et al., 2021).

Methodology

This research is a synthesis and integrative conceptual analysis based on an exhaustive review of the supplied reference list and associated core literature. The methodological approach comprises four interlinked steps: (1) systematic thematic extraction from supplied references; (2) comparative technical evaluation of

material-specific recycling and reuse pathways; (3) mapping of procurement models and organizational mechanisms that affect material selection and reuse; and (4) development of an integrative framework and roadmap that aligns material-level technical feasibility with procurement and policy levers.

Step 1 — Thematic extraction: Each supplied reference was read in full and coded for themes relevant to material processes (e.g., recycled aggregate quality, masonry reuse), product substitution (e.g., textile insulation, composite applications), systemic frameworks (e.g., reuse potential assessment), and procurement/organizational governance (e.g., cooperative procurement impacts, project delivery effects). The thematic coding allowed identification of recurring technical constraints (quality, contaminants), economic considerations (costs, profitability), lifecycle impacts, and governance issues (contracting, trust). This step drew upon empirical case studies (Guy, 2006; De Venny, 1999), laboratory and applied material research (Purnell & Dunster, 2010; Briga-Sá et al., 2013; KeskiSaari & Kärki, 2018), and procurement literature (Eriksson & Westerberg, 2011; El-Sayegh, 2008).

Step 2 — Comparative technical evaluation: Technical claims across material domains were contrasted to assess performance boundaries and processing needs. For recycled concrete and masonry, criteria included physical properties of aggregates, processing technologies (crushing, screening, contaminant removal), and applicability in structural and non-structural contexts (Purnell & Dunster, 2010; De Venny, 1999; Bojan et al., 2018). For alternative insulation materials, assessment focused on thermal properties, fire resistance, moisture behaviour and installation paradigms (Briga-Sá et al., 2013). For composites and plastics-based products incorporating waste, assessment considered feedstock quality, manufacturing adjustments, and profitability impacts (KeskiSaari & Kärki, 2018). This evaluation used qualitative comparative matrices synthesized from reported experimental outcomes and field studies.

Step 3 — Procurement mapping: Procurement and contractual models were scanned for elements that influence material flows: procurement form (traditional, design-build, collaborative), contract incentives (performance-based, whole-life cost clauses), risk allocation, and the role of a project management office (Elhag, Eapen & Ballal, 2019; Eriksson & Westerberg, 2011; Ershadi et al., 2021). Barriers and facilitators reported in reuse studies and policy analyses were catalogued, enabling linkage between procurement features and material adoption likelihood.

Step 4 — Integrative framework design: Findings from steps 1–3 were synthesized into a conceptual framework that maps technical readiness of recycled/reused options to procurement instruments and policy levers. The framework emphasizes feedback loops: procurement drives material demand and specification; material performance and quality assurance feedback into procurement standards; and organizational learning and life-cycle accounting inform future procurement cycles. The framework was iteratively refined by cross-referencing multiple sources to ensure claims were evidence-based.

Throughout the methodological process, attention was paid to contradictions and heterogeneity in the literature. Counter-evidence—such as variability in recycled aggregate performance across contexts—was documented and used to define boundary conditions for recommendations. Because this study is a literature-based synthesis, no primary experimental work was performed; instead, emphasis was placed on rigorous interrogation of secondary findings and their policy and procurement implications.

Results

The synthesis yields a multi-dimensional set of findings across technical, economic and organizational domains. These results are organized into major themes: technical viability of recycled materials; alternative insulation and composite opportunities; procurement and organizational mechanisms enabling circular outcomes; lifecycle and environmental considerations; and systemic barriers and enablers.

Technical viability of recycled concrete and masonry: The body of evidence shows that concrete recycling can produce secondary aggregates suitable for a range of applications, from unbound fill to structural concrete when appropriately processed and quality-assured (Purnell & Dunster, 2010; Bojan et al., 2018). Key variables determining suitability include residual mortar content, particle size distribution, contaminant levels (such as metals, wood or plastics), and the crushing and sieving regime used. Reclaimed masonry rubble can also be processed into reusable aggregates or crushed for fill; however, brick and masonry fragments often contain heterogeneous compositions and contaminants which necessitate careful sorting and targeted cleaning (De Venny, 1999). When recycled aggregates are used in concrete, their higher porosity and residual mortar fraction can reduce compressive strength and increase water absorption; however, such reductions are often manageable through proportioning adjustments, supplementary cementitious materials, and quality control (Purnell & Dunster, 2010; Bojan et al., 2018).

Alternative insulation from textile waste: Investigations

into textile waste as thermal insulation have demonstrated promising thermal performance, particularly in non-load-bearing applications where fire resistance and moisture management can be engineered through additives, binders or layered assemblies (Briga-Sá et al., 2013). Textile-based insulation offers the dual benefit of diverting complex waste streams from landfill while providing comparable thermal resistance per thickness to some conventional insulations. Limitations include fire performance regulation compliance and long-term durability under fluctuating humidity; these require product-level testing and certification regimes.

Wood–plastic composites and waste incorporation: Wood–plastic composites (WPCs) incorporating post-consumer and post-industrial wastes present an opportunity to valorize wood residues and plastic waste streams, although the profitability and technical performance depend markedly on feedstock consistency, processing technology, and market acceptance (Keskisaari & Kärki, 2018). The literature indicates that substituting virgin materials with waste inputs can maintain acceptable mechanical properties in many product classes if processing parameters are optimized.

Reuse potential of building elements: A systemic assessment framework for reuse potential of building elements emphasizes criteria such as technical condition, remaining service life, traceability, standardization, and market demand (Durmisevic et al., 2017). Deconstruction-oriented practices that prioritize component salvage (e.g., facades, windows, doors, structural steel) can retain high value if supply chains, storage logistics and quality assurance are established (Guy, 2006; Hobbs & Adams, 2017). However, reuse is more complex for elements integrated with composite systems or where traceability and code compliance are ambiguous.

Procurement and project delivery influences: Procurement models strongly influence the incorporation of reused and recycled materials. Cooperative procurement procedures and collaborative contracting are correlated with improved project performance in integrating sustainability objectives, because they incentivize joint problem-solving and risk-sharing that can accommodate non-standard material flows (Eriksson & Westerberg, 2011; Eriksson & Laan, 2007). A project management office can play a pivotal role in implementing circular procurement strategies by consolidating expertise, standardizing specifications, and monitoring performance (Ershadi et al., 2021). Conversely, adversarial contracting and rigid procurement specifications focusing solely on lowest upfront cost

act as barriers to circular materials (El-Sayegh, 2008; Eyiah-Botwe, Aigbavboa & Thwala, 2015).

Lifecycle and environmental considerations: Life-cycle assessment literature offers mixed, context-dependent conclusions regarding environmental benefits of using recycled materials, driven by system boundary choices, transport distances, and assumptions about avoided impacts from virgin material production (Bribián, Capilla & Usón, 2011; Buyle et al., 2013). Nonetheless, the majority of analyses suggest that for many materials—particularly heavy, resource-intensive ones like concrete—recycling and reuse can reduce embodied energy and CO₂ when implemented with efficient processing and minimal additional transport (Bilec et al., 2006; Bribián, Capilla & Usón, 2011). Dynamic material flow analysis underscores the importance of stock accumulation and retirement rates in determining long-term resource availability for reuse (Bergsdal et al., 2007).

Barriers and enablers: Main barriers include technical variability and contamination of recycled feedstocks, regulatory ambiguity, lack of quality assurance standards, fragmented supply chains, and procurement practices that do not reward whole-life performance (Purnell & Dunster, 2010; De Venny, 1999; Hobbs & Adams, 2017). Enablers include standardized testing and certification, procurement clauses that reward low whole-life costs and environmental performance, deconstruction training programs, and facility investments in advanced sorting and processing technologies (Guy, 2006; Durmisevic et al., 2017; Ershadi et al., 2021).

Discussion

This section interprets the results through theoretical lenses drawn from industrial ecology, procurement theory, and life-cycle thinking, and presents a detailed roadmap for bridging technical potential with procurement and policy mechanisms.

Theoretical implications: Industrial ecology frames built environments as material stocks and flows where circularity emerges from closing loops and preserving value in assets (Boulding, 1966; By et al., 1995). Our synthesis supports the view that built stock retention and component reuse are high-value strategies within industrial ecology because they preserve embodied energy and reduce extraction pressure on primary resources (Bergsdal et al., 2007). However, unlike simpler product cycles, buildings present heterogeneity in materials, assembly methods and ownership structures that complicate loop closure. Therefore, theoretical frameworks must accommodate multi-actor networks, contractual dynamics and information asymmetries. Procurement and contract theory add

that incentives and risk allocation structures directly shape actor behaviour: procurement mechanisms that share risk and reward sustainability outcomes foster innovation and allow the adoption of less standardized circular materials (Eriksson & Westerberg, 2011; Elhag, Eapen & Ballal, 2019).

Reconciling life-cycle evaluations: Life-cycle assessment offers critical insights but can produce divergent outcomes depending on methodological choices (Bribián, Capilla & Usón, 2011; Buyle et al., 2013). The practitioner needs are pragmatic: procurement bodies require comparability and reliability. To reconcile LCA heterogeneity, we recommend standardized LCA boundary conditions for procurement decision-making that include consistent system boundaries (cradle-to-gate vs cradle-to-grave), explicit transport assumptions, and sensitivity analyses for key uncertain parameters such as replacement rates and contaminant removal energy. Dynamic material flow analyses should be integrated to capture stock effects and temporal availability of secondary materials (Bergsdal et al., 2007).

Procurement as the linchpin: The evidence clearly situates procurement at the heart of successful circular transitions. Procurement frames what is acceptable, rewarded, and contractually enforced. Collaborative procurement procedures—such as alliancing, integrated project delivery, and performance-based contracting—reduce adversarial relationships and facilitate the sharing of risk associated with using recycled materials (Eriksson & Laan, 2007; Eriksson & Westerberg, 2011). A project management office with explicit circularity mandates provides continuity and technical capacity across projects, enabling standardized specifications for recycled materials, establishing supplier networks, and measuring outcomes (Ershadi et al., 2021). Equally important are contract clauses that value whole-life performance and environmental metrics, rather than narrow first-cost comparisons (El-Sayegh, 2008).

Operational roadmap: From the synthesis, a multi-pronged roadmap emerges that aligns material-level interventions with procurement reforms and enabling policies. Key elements include:

1. **Quality assurance systems for recycled materials:** Establish standardized testing protocols and certification pathways for recycled aggregates, masonry-derived materials, and textile-based insulations to reduce uncertainty and enable market acceptance (Purnell & Dunster, 2010; De Venny, 1999; Briga-Sá et al., 2013).

2. **Procurement specification reform:** Update procurement specifications to allow graded

acceptance of recycled materials, include whole-life cost assessment, and introduce bonuses or price adjustments for circular outcomes. Promote collaborative contracting models that align incentives (Eriksson & Westerberg, 2011; Elhag, Eapen & Ballal, 2019).

3. **Deconstruction-first policies and training:** Incentivize deconstruction over demolition through permits, tax credits, or procurement preferences for projects that utilize reclaimed elements; develop training programs for deconstruction techniques and salvage logistics (Guy, 2006; Hobbs & Adams, 2017).

4. **Investment in processing infrastructure:** Public-private partnerships to finance advanced sorting, crushing and contaminant removal facilities that increase the yield and quality of secondary aggregates and recycled feedstocks (Purnell & Dunster, 2010).

5. **Market-making through aggregated demand:** Public procurement can aggregate demand for recycled materials across multiple projects, reducing market fragmentation and improving economies of scale (Ghaffar, Burman & Braimah, 2020).

6. **Integrated measurement and reporting:** Standardize metrics for circularity, combine LCA outcomes with performance monitoring, and require reporting in procurement contracts to create feedback loops for continuous improvement (Bribián, Capilla & Usón, 2011).

Addressing limitations and counter-arguments: Critics might argue that recycled materials carry unacceptable performance risks for certain structural applications or that the energy required for processing reduces environmental benefits. The literature indicates that such risks can be managed: appropriate processing, use-case selection (structural vs non-structural), and admixture strategies can mitigate performance concerns (Purnell & Dunster, 2010; Bojan et al., 2018). Regarding energy intensity, robust LCA and transport optimization can ensure that recycling yields net environmental benefits in most contexts, but this is sensitive to transport distances and processing energy; hence localized processing infrastructure and supply aggregation are critical (Bribián, Capilla & Usón, 2011; Bergsdal et al., 2007).

Institutional and behavioral barriers also deserve attention. Fragmented supply chains, short-term decision-making and misaligned incentives often thwart circular adoption (Hobbs & Adams, 2017; Eyiah-Botwe, Aigbavboa & Thwala, 2015). These require policy instruments and capacity building; for example, training procurement officers to evaluate whole-life costs or establishing circularity champions within organizations (Ershadi et al., 2021).

Policy implications: Effective policies should combine regulation with market incentives. Regulations can standardize quality and permit reuse, while market instruments (procurement preferences, subsidies for processing infrastructure) can accelerate adoption. Additionally, information transparency—databases of salvaged elements, digital passports for material provenance—can greatly improve traceability and trust in reused materials (Durmisevic et al., 2017).

Future research directions: Empirical piloting of the proposed framework is essential. Research should embed material-level testing within procurement pilots across multiple projects to evaluate real-world performance, cost and organizational constraints. Comparative studies across jurisdictions can elucidate how regulatory and market contexts influence outcomes. Further work is also needed to refine dynamic LCAs that capture temporal aspects of stock reuse and to evaluate social dimensions such as labour market impacts of deconstruction industries.

Conclusion

The transition to circular construction is both technically feasible and institutionally challenging. Recycled concrete and masonry, textile-based insulation, and waste-inclusive composites offer tangible pathways to reduce embodied impacts and valorize waste streams when quality is assured and supply chains structured. However, material-level advances alone are insufficient. Procurement models and organizational capacities are the critical levers that will determine whether technical possibilities scale into systemic change. Collaborative procurement, project management offices oriented to sustainability, quality assurance systems, and market-making through aggregated demand and processing infrastructure are central components of an integrated strategy. This paper synthesizes diverse strands of literature into a coherent framework and roadmap that links technical options to procurement and policy instruments, offering a practical pathway for stakeholders to accelerate circularity in the built environment. To progress, coordinated action across industry, government and research is required: rigorous pilots that integrate material testing, procurement reform and lifecycle monitoring will be the crucible for demonstrating scalable circular construction.

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