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Integrating Circularity and Innovative Materials in Sustainable Construction: A Comprehensive Framework for Design, Procurement, and End-of-Life Management

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ABSTRACT

The construction sector faces a dual imperative: to accommodate growing infrastructure needs while radically reducing environmental impacts through material innovation and circular economy approaches. This research article synthesizes theoretical foundations, material-specific studies, procurement policies, life cycle assessment (LCA) findings, and practice-focused case evidence to develop a coherent, publication-ready framework for integrating novel green materials and circular procurement into the lifecycle of buildings. Drawing strictly from the provided literature, the article constructs an integrated narrative that links material science innovations—such as recycled aggregate concretes, geopolymer matrices with industrial by-products, wood-chip and demolition timber concretes, and thermoplastic composite prototypes—with process and policy mechanisms including procurement reform, supply-chain coordination, and LCA-driven end-of-life strategies. The methodology is abductive and qualitative, combining systematic combining of case-oriented insights with interpretive synthesis to generate actionable propositions for design, procurement and end-of-life decision-making (Dubois & Gadde, 2002; Creswell & Poth, 2016). Key results indicate that material substitution and reuse can be made technically viable without sacrificing structural performance when combined with adaptive procurement models and targeted policy levers (De Luca et al., 2017; Francesconi, 2012; de Brito et al., 2006). The discussion critically examines trade-offs—durability versus embodied carbon, operational performance versus reuse potential—and points to limitations in existing LCA practice for end-of-life stages, arguing for procedural and methodological improvements (Pierluca et al., 2017; Droege et al., 2021). The article concludes with a detailed, multi-actor implementation roadmap that links design-stage circularity checks, procurement incentives, and end-of-life planning to ensure material cascades and minimize waste. This synthesis contributes a theoretically informed and practically applicable template for researchers, practitioners, and policy-makers aiming to operationalize circular construction while maintaining structural and economic viability.

KEYWORDS

Circular economy; green building materials; recycled aggregates; life cycle assessment; procurement; geopolymer; end-of-life management

INTRODUCTION

The global construction sector is simultaneously responsible for a significant share of resource extraction, material consumption and waste generation, and a major proportion of greenhouse gas emissions associated with material production and building operations. Addressing this paradox—how to sustain building performance while materially transforming the sector toward circularity—requires an integrated approach that spans material innovation, procurement reform, lifecycle thinking and end-of-life strategies (De Luca et al., 2017; Pierluca et al., 2017). The literature indicates multiple parallel advances: new composite and geopolymer materials that replace or reduce Portland cement content, reuse-oriented aggregates from demolition, thermoplastic composites using mixed waste plastics, and novel lightweight block production that uses industrial by-products (Xanthos et al., 2002; Posi et al., 2016; Pangdaeng et al., 2014). At the same time, procurement practices and public sector policy choices either accelerate or retard circular adoption depending on how they treat innovation, risk, and lifecycle value (Bima et al., 2015; Cattolica, 2018).

This article responds to a pressing problem statement: despite promising advances at the material and process level, the mainstreaming of circular materials in construction is limited by fragmentation across design, procurement, supply chains, and end-of-life systems. The literature shows that while individual material technologies can perform satisfactorily in laboratory or prototype contexts, systemic adoption is constrained by procurement rules, supply-chain inertia, uncertain durability evidence, and the inadequacy of LCA methods to fully capture end-of-life benefits (Francesconi, 2012; Pierluca et al., 2017; Droege et al., 2021). This creates an important research gap: a need for an integrated, evidence-based framework that connects material-level data, procurement mechanisms, and lifecycle assessment to practical end-of-life management. The aim of this article is therefore to construct such a framework grounded strictly in the provided references, elaborating in detail the theoretical foundations, methodological reasoning, and practical implications necessary for both research progression and industry uptake.

The contribution is threefold. First, the paper synthesizes dispersed material studies—on recycled aggregate concretes, wood-chip concrete, geopolymer blocks, and thermoplastic composites—into a cohesive typology of green building materials and situates each within lifecycle and structural performance considerations (Kasai et al., 1995; Francesconi, 2012; Posi et al., 2016; Xanthos et al., 2002). Second, it interrogates procurement and supply-chain mechanisms that enable circular adoption, building on comparative policy reviews and procurement studies which highlight public sector levers and barriers (Bima et al., 2015; Cattolica, 2018; De Valence, 2010). Third, it integrates LCA insights—especially those pertaining to the end-of-life phase—into an operational roadmap that prescribes actions at design, procurement and demolition stages to secure material circularity (Pierluca et al., 2017; Berggren et al., 2013).

The remainder of the article proceeds as follows. The methodology section details the abductive, qualitative synthesis approach and the interpretive tools used to connect disparate empirical findings. The results section presents a descriptive analysis of material typologies, procurement frameworks, and lifecycle implications. The discussion provides a deep interpretation of trade-offs, methodological limitations in existing LCA practices, and the strategic conditions required for scalable circularity. The paper concludes with explicit recommendations and a proposed multi-stakeholder roadmap for implementation and research.

METHODOLOGY

This research adopts an abductive, qualitative synthesis methodology that combines systematic combining of case-oriented evidence with interpretive theoretical elaboration (Dubois & Gadde, 2002; Creswell & Poth, 2016). Abductive reasoning is particularly suitable here because the task is to generate an integrative framework from partial and heterogeneous evidence—laboratory studies, LCA case analyses, procurement policy reviews, and thesis-level structural investigations. The method prioritizes theoretical coherence and practical salience: empirical observations are juxtaposed with theory to produce new, plausible explanations which are both grounded in evidence and generative of testable propositions.

Data Sources and Scope Restrictions

The corpus is limited to the references provided and no external literature. This constraint ensures the article's fidelity to the specified dataset, while necessitating careful cross-referencing and interpretive linking between sources. The included studies span material experimentation (e.g., recycled aggregate concretes, geopolymer matrices), LCA case studies focused on end-of-life phases, procurement policy analyses and socio-technical accounts of waste in construction. Sources vary by methodology—experimental, case-study LCA, policy review, and theses—and each contributes distinct types of evidence: mechanical performance data, lifecycle emissions accounting, procurement experience, and contextual barriers to circular adoption.

Analytic Process

The analytic process unfolded in four iterative stages:

1. Material Typology Extraction: Each materials-focused study was analyzed to extract core attributes: composition, production process, mechanical properties, reported durability, and stated limitations (Kasai et al., 1995; Francesconi, 2012; Posi et al., 2016; Pangdaeng et al., 2014; Xanthos et al., 2002; Keskisaari & Kärki, 2016). This allowed classification into categories such as recycled-aggregate concrete, geopolymer-based masonry, timber-reinforced concretes, and thermoplastic composites.

2. Lifecycle and LCA Synthesis: LCA-focused sources were examined to extract methodologies used in end-of-life assessment, inventory boundaries, treatment of recycling credits, and reported impacts. The LCA of a residential building end-of-life (Pierluca et al., 2017) and life-cycle analyses moving toward net-zero frameworks (Berggren et al., 2013) were used as templates to understand how end-of-life scenarios alter total lifecycle burdens and to identify methodological gaps.

3. Procurement and Supply-Chain Integration: Procurement and policy papers provided insight into public-sector levers, procurement models, and institutional barriers. These materials were analyzed to identify mechanisms (e.g., circular public procurement, procurement risk allocation, incentives for reuse-oriented contracting) that could operationalize material innovations (Bima et al., 2015; Cattolica, 2018; Droege et al., 2021; De Valence, 2010).

4. Abductive Framework Development: The prior three streams were combined iteratively. For each material typology, potential procurement mechanisms and LCA-end-of-life scenarios were paired to produce policy and practice propositions. The abductive loop—moving between specific findings and higher-order constructs—generated the integrated framework and implementation roadmap offered in the results and discussion sections (Dubois & Gadde, 2002).

Quality Assurance and Validity Considerations

Given the exclusive reliance on the provided literature, validity was addressed through triangulation across different types of sources. For instance, mechanical performance claims in laboratory studies were cross-checked with LCA reports where possible to verify whether materials' environmental advantages were empirically justified once lifecycle boundaries and end-of-life outcomes were considered (Francesconi, 2012; Pierluca et al., 2017). Interpretive coherence was further triangulated with procurement and policy literature to ensure that technical recommendations were matched by realistic implementation pathways (Bima et al., 2015; Cattolica, 2018).

Ethical and Practical Limits of the Method

The approach is interpretive and synthetic rather than empirical in the sense of new laboratory or field experimentation. This is a deliberate research design given the instruction to base the paper strictly on the supplied references. As such, claims are inferential and contingent upon the evidence available in those sources; gaps in empirical specificity (e.g., exact compressive strengths under diverse mix designs or regional cost multipliers) are acknowledged and discussed as limitations. Where the evidence base is thin or ambiguous, the article explicitly identifies uncertainty, highlights plausible alternative interpretations, and recommends empirical studies to close these gaps.

RESULTS

The results present a descriptive and integrative analysis centered on three interlinked domains: (1) green building material typologies and performance implications, (2) lifecycle consequences with emphasis on end-of-life, and (3) procurement and supply-chain mechanisms that can enable or hinder circular adoption.

1. Green Building Material Typologies and Performance

A. Recycled Aggregate Concretes (RACs)

Recycled aggregate concretes, produced by substituting natural coarse and/or fine aggregates with aggregates recovered from demolished concrete, are extensively discussed across the provided literature (de Brito et al., 2006; Layachi et al., 2015; Francesconi, 2012). De Brito et al. (2006) demonstrate that multiple recycling cycles are theoretically feasible, though mechanical properties may decline progressively due to residual mortar content and increased porosity. Francesconi (2012) provides focused structural engineering insights, showing that appropriately designed mixes with grading adjustments and additional cementitious binders can achieve structural viability. Layachi et al. (2015) further analyze mechanical properties and durability, showing that careful control of aggregate quality and mix proportions can mitigate durability concerns.

Key attributes and implications: RACs offer immediate benefits in resource conservation and reduced natural aggregate extraction (de Brito et al., 2006). However, trade-offs include potentially lower compressive strength and increased water absorption, which can affect long-term durability. Mitigation strategies involve controlled processing to remove adhered mortar, supplementary cementitious materials to enhance matrix densification, and design adjustments to account for altered modulus and strength.

B. Wood-Chip Concrete and Demolished Timber Aggregates

Kasai et al. (1995) describe production processes for wood-chip concrete that combine wood chips—often from demolition timber—with cementitious matrices to form composites with distinctive bending and compressive strength profiles. These materials exhibit advantages in thermal insulation and reduced density, presenting opportunities for non-structural to semi-structural applications. Francesconi (2012) also evaluates recycled timber within concrete matrices, emphasizing the need to reconcile moisture sensitivity and interaction with cement hydration products.

Key attributes and implications: Wood-chip concretes deliver weight reductions and improved thermal performance, but pose challenges in dimensional stability, moisture susceptibility, and sometimes lower strength compared to conventional concrete. Practical use-cases include partition walls, thermal-insulating panels and lightweight infill blocks where structural demands are moderate.

C. Geopolymer and Fly-Ash Based Masonry

Studies on geopolymer formulations—particularly those employing high-calcium fly ash with Portland cement additives—suggest promising mechanical and durability properties when cured under optimized conditions (Pangdaeng et al., 2014; Posi et al., 2016). Pangdaeng et al. (2014) emphasize that curing conditions (temperature, humidity, duration) critically influence geopolymerization kinetics and resulting mechanical performance. Posi et al. (2016) demonstrate pressed lightweight geopolymer blocks combining fly ash, Portland cement and recycled lightweight concrete, indicating viable compressive strengths for masonry applications.

Key attributes and implications: Geopolymer matrices substantially reduce reliance on Portland cement, lowering embodied carbon when using industrial by-products. However, consistent production quality requires controlled curing regimes and careful mix design. The inclusion of recycled aggregates introduces additional variability that must be addressed through process controls.

D. Thermoplastic Composites Using Mixed Waste Plastics

Xanthos et al. (2002) present prototypes for building applications based on thermoplastic composites containing mixed waste plastics. These composites can be extruded or molded into cladding, panels and non-load-bearing components. Keskisaari & Kärki (2016) expand on the raw material potential of recyclable feedstocks for fiber composites, assessing availability, collection logistics, and material variability.

Key attributes and implications: Thermoplastic composites allow large-scale diversion of mixed plastic waste from landfill through the creation of durable, moisture-resistant building components. Challenges include heterogeneous feedstock quality, potential thermal degradation during processing, and uncertainties about long-term UV and mechanical durability in certain exposure scenarios.

2. Lifecycle Consequences Emphasizing End-of-Life

A. End-of-Life LCA and Recycling Credits

Pierluca et al. (2017) conduct an LCA of the end-of-life phase of a residential building, illustrating how demolition strategies (selective demolition, deconstruction, mechanical demolition) markedly affect end-of-life environmental profiles. The study highlights the importance of accounting for recycling credits, transport burdens for recovered materials, and treatment hierarchies (reuse > recycling > energy recovery > landfill). Berggren et al. (2013) extend lifecycle thinking toward net-zero energy buildings and emphasize that material and end-of-life choices can materially alter the feasibility of net-zero targets when included in full lifecycle assessments.

Key attributes and implications: End-of-life decisions are decisive. Selective demolition enabling high-quality material recovery aligns with circular objectives, but often increases short-term costs and complexity. LCA studies that incorporate realistic recycling yields, transport distances, and reprocessing energy requirements provide a more faithful estimate of lifecycle benefits than simplistic assumptions about universal recycling.

B. Multiple Recycling and Aggregate Quality Degradation

De Brito et al. (2006) investigated multiple recycling cycles of concrete coarse aggregates, finding that while recycling is possible several times, aggregate quality and mechanical performance show cumulative degradation. This behavior complicates LCA crediting: material recovered at second or third cycles may deliver lower service life, thereby altering the net environmental payback.

Key attributes and implications: LCA practitioners and designers must model not only the immediate substitution of virgin aggregates but also the gradual degradation of mechanical properties across successive reuse cycles, which can shorten the secondary material’s service life and require earlier replacement or supplemental reinforcement.

C. Operational vs. Embodied Trade-Offs

Several sources (Berggren et al., 2013; Pierluca et al., 2017) point out a fundamental trade-off: strategies that reduce embodied impacts (e.g., cement substitution) might slightly alter operational performance (e.g., thermal mass changes), while certain lightweight or highly insulative materials may increase embodied energy due to manufacturing complexity. The holistic lifecycle perspective is essential to avoid problem-shifting.

3. Procurement, Policy and Supply-Chain Mechanisms

A. Public Procurement as a Lever for Circular Adoption

Cattolica (2018) explores circular public procurement in Sweden and Scotland, identifying how procurement frameworks can catalyze market development for circular materials. Bima et al. (2015) provide an appraisal of procurement policies in Nigeria, illustrating the widespread influence of procurement rules on implementation outcomes. De Valence (2010) highlights how innovation in procurement correlates with industry development, particularly when risk allocation and performance metrics are aligned with lifecycle outcomes.

Key attributes and implications: Public procurement has latent power to shift demand toward circular products by redefining selection criteria (e.g., lifecycle cost and environmental performance rather than lowest first-cost), including requirements for reclaimed content or end-of-life take-back, and awarding innovation premiums. However, procurement change is politically and administratively contentious; capacity-building and clear evaluation methodologies are prerequisites.

B. Supply-Chain Coordination and Risk Management

Chopra & Meindl (2007) provide supply-chain theory relevant to construction materials contexts: effective circular adoption requires coordination across suppliers, processors, transporters and end-users. Droege et al. (2021) articulate practical challenges in implementing circular economy assessments in public sector organizations, including data gaps, institutional silos, and capacity constraints.

Key attributes and implications: Building a circular supply chain demands investments in traceability, quality control of recovered materials, logistics for selective demolition and transport, and contractual mechanisms that allocate risk (e.g., warranties for secondary materials). Without these, the perceived risk from clients and contractors hinders adoption.

C. Behavioral and Institutional Barriers to Waste Reduction

Alwi et al. (2002), Begum et al. (2009), and other sources reflect attitudinal and behavioral factors that impede waste reduction in construction. These include entrenched contractor routines, misaligned incentives that prioritize short-term cost, and lack of client demand for circular products.

4. Synthesis: Emergent Patterns and Systemic Findings

By juxtaposing material-level feasibility with lifecycle and procurement considerations, several systemic findings emerge:

- Materials with clear performance parity and well-documented lifecycle advantages (e.g., well-formulated geopolymers using high-quality fly ash) are more likely to be adopted when supported by procurement standards and quality assurance protocols (Pangdaeng et al., 2014; Posi et al., 2016).

- Recycled aggregate concretes can be structurally viable for many applications when design adjustments and enhanced mix controls are employed; however, their lifecycle benefits depend critically on realistic end-of-life treatment assumptions and an understanding of multiple recycling dynamics (de Brito et al., 2006; Francesconi, 2012).

- Thermoplastic composites and wood-chip concretes provide important niches—non-structural components, cladding, infill panels, and insulation—where circular feedstocks can be channeled effectively with relatively lower barriers to safety certification; their adoption is conditioned by supply-chain logistics for waste plastic collection and timber treatment (Xanthos et al., 2002; Kasai et al., 1995; Keskisaari & Kärki, 2016).

- Procurement reform is a necessary, though not sufficient, condition. Effective procurement that prioritizes lifecycle performance must be complemented with technical standards, demonstrator projects, and targeted incentives to address perceived risks and build market confidence (Cattolica, 2018; De Valence, 2010; Bima et al., 2015).

These findings supply the empirical content for the integrated, action-oriented framework elaborated in the Discussion.

DISCUSSION

The analysis above reveals both technical promise and systemic constraints. The discussion extends the descriptive findings into deeper theoretical interpretation, explores counter-arguments, unpacks limitations of the evidence, and outlines future research and policy directions.

1. Theoretical Interpretation: Material Substitution as a Socio-Technical Transition

The adoption of circular materials in construction should be interpreted not merely as an engineering substitution but as a socio-technical transition requiring alignment across technology, markets, institutions, and user practices. The literature provides components of this transition: material prototypes (Xanthos et al., 2002; Posi et al., 2016), LCA evidence that clarifies environmental trade-offs (Pierluca et al., 2017), and procurement mechanisms that can shift market incentives (Cattolica, 2018; De Valence, 2010). From a transition theory perspective, laboratory-validated materials represent niche innovations that must interact with broader regime elements—construction norms, procurement channels, and regulatory standards—to scale (Dubois & Gadde, 2002).

A critical insight is that lab-scale performance is necessary but not sufficient. For example, a geopolymer block with acceptable compressive strength still faces regime-level barriers: absence of contractual standards for geopolymer masonry, lack of long-term durability data demanded by insurers, and supply-chain inconsistencies in fly ash quality. Thus, upscaling requires coordinated action across knowledge production (further trials and long-term monitoring), standards development, and procurement that creates market pull.

2. Trade-offs and Counter-Arguments

A balanced evaluation must confront trade-offs and credible counter-arguments. One common critique is that recycled materials, while reducing virgin resource demands, introduce performance uncertainties that could increase maintenance demands or reduce structural safety margins. The empirical evidence suggests that these risks can be managed through design adjustments, quality control and conservative use-cases (de Brito et al., 2006; Francesconi, 2012). Yet uncertainty remains regarding long-term performance under diverse exposure conditions—information that only long-term monitoring or accelerated ageing tests can resolve.

Another counter-argument is cost: selective demolition and high-quality material processing can be more expensive in upfront terms, undermining economic competitiveness. Pierluca et al. (2017) illustrate that lifecycle benefits may offset upfront costs, but such savings are contingent upon correct accounting of reuse benefits and local processing infrastructure. Therefore, economic evaluation must move beyond first-cost logic to lifecycle costing frameworks and incorporate externalities such as landfill avoidance and carbon pricing where applicable.

A further counterpoint questions the scale of available secondary feedstocks. Keskisaari & Kärki (2016) analyze raw material potentials for fiber composites, indicating constraints in consistent feedstock volumes and qualities. This suggests strategic targeting: prioritize circular materials where local feedstock availability is sufficient and logistic costs are low, while simultaneously investing in collection and sorting systems in high-demand regions.

3. Methodological Limitations and LCA Challenges

The review surfaces several methodological limitations in existing LCA practice. Pierluca et al. (2017) and Berggren et al. (2013) note that LCA outcomes are sensitive to boundary choices, recycling credit assumptions, and allocation methods for co-products. Where recycling credits are applied optimistically—assuming full substitution and high-quality secondary aggregates—LCA outcomes can overstate environmental benefits. Conversely, overly conservative treatment may undervalue real gains. De Brito et al. (2006) highlight that multiple recycling cycles complicate this further: each reuse phase may lower quality and lifetime benefits.

To improve LCA practice for circular construction, the literature suggests several methodological refinements: (a) inclusion of realistic end-of-life scenarios with graded yield and quality factors for recovered materials, (b) explicit modeling of service-life changes for reused materials, (c) sensitivity analyses for transport and processing energy under different spatial scenarios, and (d) harmonization of allocation methods for recycling credits across studies (Pierluca et al., 2017; Berggren et al., 2013). These refinements enhance comparability and reduce the risk of misleading policy conclusions.

4. Procurement as a Mechanism for Systemic Change

Procurement emerges as a pivotal lever in the transition. Cattolica (2018) demonstrates that circular public procurement can create demand for circular products, provided evaluation criteria reward lifecycle and social benefits. De Valence (2010) and Bima et al. (2015) highlight practical pathways and barriers: public buyers need clear evaluation frameworks, legal comfort with innovative materials, and procurement officers must be trained to evaluate lifecycle evidence.

Operationally, procurement can be redesigned to support circular materials via several instruments. Contractual clauses requiring reclaimed content thresholds, performance-based contracts that measure lifecycle outcomes, incentives for selective demolition and material take-back, and pilot projects that de-risk new materials all serve to lower market entry barriers. Yet procurement change must go hand-in-hand with standards and testing regimes that reduce perceived technical risk.

5. Implementation Roadmap: Linking Design, Procurement and End-of-Life

Drawing from the synthesized evidence, an implementation roadmap includes five core components:

A. Design-Stage Circularity Checklists: Encourage designers to evaluate material choices against a circularity checklist that includes resource origin, recyclability, expected service life, repairability, and disassembly potential. Materials such as geopolymer blocks and thermoplastic panels should be matched to applications where their lifecycle profiles and performance characteristics are optimal (Pangdaeng et al., 2014; Xanthos et al., 2002).

B. Procurement Reforms: Revise procurement criteria to incorporate lifecycle cost and environmental performance. Use pilot procurements to create early market demand and include contractual provisions that share risk between suppliers and clients for new materials (Cattolica, 2018; De Valence, 2010).

C. Selective Demolition and Logistics: Develop guidelines and incentive schemes for selective demolition to maximize material recovery quality. This includes training demolition contractors, investing in onsite sorting infrastructure, and creating aggregation centers for secondary materials (Pierluca et al., 2017).

D. Quality Assurance and Standards: Establish standards and certification pathways for secondary materials, including performance testing protocols, traceability systems, and warranties that reflect realistic performance expectations (Francesconi, 2012; de Brito et al., 2006).

E. Enhanced LCA and Monitoring: Use improved LCA protocols that account for multiple recycling cycles, disaggregated transport impacts, and variable recovery yields. Complement LCA with long-term monitoring programs for novel materials to build a robust evidence base on durability and in-service performance (Pierluca et al., 2017; Berggren et al., 2013).

6. Limitations of This Synthesis and Future Research Needs

This synthesis is constrained by the available literature, which—while diverse—does not always provide uniform empirical detail necessary for definitive quantitative conclusions. For instance, the mechanical performance of recycled aggregate concretes varies by local aggregate quality and processing; thus, region-specific empirical studies are necessary to validate the proposed design adjustments. Likewise, long-term durability data for thermoplastic composites and wood-chip concretes in varied climates are limited. The policy literature provides instructive case studies but lacks controlled comparative evaluations of procurement instruments and their long-term market impacts.

Future research priorities derived from the synthesis include:

● Longitudinal monitoring of structures incorporating recycled aggregates, thermoplastic composites, and geopolymer masonry to document performance over time and under varied climates.

● Controlled comparative LCAs that systematically vary end-of-life scenarios, transport distances, and recovery yields to quantify sensitivity and provide robust policy guidance.

● Pilot procurement experiments that test different contractual instruments, risk-sharing arrangements, and evaluation criteria to observe market responses.

● Supply-chain feasibility studies focusing on logistics, aggregation centers, and localized sorting infrastructures to bridge gaps between material availability and construction demand.

CONCLUSION

This article has synthesized material innovation studies, lifecycle assessments, and procurement policy analyses to present a holistic framework for integrating circularity into building design, procurement and end-of-life management. The evidence shows that a range of green materials—recycled aggregate concretes, geopolymer blocks, wood-chip concretes, and thermoplastic composites—have technical potential to reduce the environmental footprint of construction. However, realizing these benefits at scale requires aligning material performance evidence with procurement instruments, standards development, and improved LCA practice that realistically models end-of-life outcomes.

The proposed roadmap—spanning design-stage circularity checks, procurement reform, selective demolition logistics, quality assurance, and enhanced LCA and monitoring—offers practical steps for policy-makers, procurers, designers and suppliers. The research emphasizes that circular transition in construction is a socio-technical challenge: technical viability must be accompanied by market formation, institutional change and behavioral shifts.

Finally, the article identifies clear research priorities—long-term performance monitoring, robust comparative LCA, procurement experimentation and supply-chain feasibility studies—that will strengthen the empirical basis for system-level decisions. Together, these measures will help translate promising material innovations into durable, scalable circular solutions for the built environment.

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