

BUILDINGS AS MATERIAL RESOURCES AND ASSOCIATED SUSTAINABLE PRACTICES

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ABSTRACT

This paper investigates methodological approaches to studying sustainable practices in the construction sector, focusing on understanding buildings as material resources. Recycling construction materials, Design for Deconstruction (DfD), and urban mining represent methodological principles and actions that address buildings as material banks on different levels.

The research is motivated by contemporary strategies for construction waste management and European Union directives. Even the latest version of EPBD issued in 2024, primarily addresses energy efficiency-related challenges, emphasizing the importance of whole-life-cycle emissions and promoting the concept of buildings as material banks to support sustainable resource management.

Three complementary levels of intervention are highlighted: material recycling, Design for Deconstruction (DfD), and urban mining. Material recycling focuses on reducing CO₂ emissions and dependency on natural resources. DfD facilitates modular building design aimed at enabling the disassembly and reuse of a wide range of building components. Urban mining, as the broadest framework, considers the building stock as a material bank, offering opportunities for sustainability at the urban scale.

The findings identify key challenges, including material quality degradation and high initial implementation costs. This paper highlights the necessity of an interdisciplinary approach, the development of tailored standards and technologies, and the regional adaptation of global methodologies. These conclusions provide a foundation for future research and practical strategies to enhance construction waste management and advance circular economy principles.

KEYWORDS _ *Urban mining, Construction waste recycling, Design for Deconstruction*

INTRODUCTION

The built environment is both a primary driver of material resource depletion and a largely untapped source of recoverable value. Globally, construction activities account for nearly 30% of total waste generation and consume about 40% of all extracted raw materials (European Commission, 2020). As Geissdoerfer et al. (2017) argue, this is emblematic of the broader linear economy paradigm—extract, produce, discard—which fails to consider the potential of buildings as ongoing material reservoirs.

To address this systemic inefficiency, the revised Energy Performance of Buildings Directive (EPBD 2024) emphasizes whole-life-cycle emissions and formally introduces the concept of buildings as “material banks”, encouraging designs that facilitate the reuse and recovery of components at end-of-life (European Union, 2024, Art. 7). This paradigm shift aligns with broader objectives outlined in the European Green Deal and the Circular Economy Action Plan (2020), both of which urge the construction sector to move beyond energy-centric metrics and treat the built environment as a dynamic reservoir of recoverable material resources (European Commission, 2020). Collectively, these policy signals reinforce the need for integrated methodologies that operationalize circularity across the entire building lifecycle.

This paper proposes a conceptual framework for resource recovery in architecture by examining three interdependent strategies—urban mining, design for deconstruction (DfD), and recycling. Functioning across city, component, and material scales, these methodologies collectively support circularity in the built environment. Informed by recent policy developments such as the EPBD 2024 and academic discourse on circular design and material reuse (Calkins, 2009; Kakkos et al., 2020), the paper clarifies their methodological roles, scale interactions, and potential for integration into future-oriented construction practice.

METHODOLOGY

This study adopts a conceptual and comparative methodology, grounded in a synthesis of academic literature, EU policy frameworks, and strategic documents on circular construction. Rather than analysing empirical case studies, the goal is to identify how the built environment can transition from a linear to a circular system through methodologically distinct but interdependent strategies.

Literature was selected based on its relevance to different spatial scales—urban, component, and material—and its use of tools such as Life Cycle Assessment (LCA), Material Flow Analysis (MFA), disassembly metrics, and digital inventory systems. Particular emphasis was placed on sources that conceptualize buildings as dynamic repositories of material value, rather than as static structures (Calkins, 2009; Panizza & Nik-Bakht, 2024).

This methodological synthesis provides the foundation for a scalable conceptual model in which urban mining, design for deconstruction (DfD), and recycling are framed as complementary strategies. Each method operates at a distinct scale yet contributes to an integrated circular construction system. Their systemic relevance lies in the coordination of planning, design, and material recovery, as highlighted in recent theoretical and policy literature (Nicholson & Miatto, 2024; EU, 2024).

THREE METHODOLOGIES ACROSS THREE SCALES

The transition toward circular construction requires diverse methodological interventions across various spatial and operational scales. This section explores three complementary strategies—urban mining, design for deconstruction (DfD), and recycling—each situated at a distinct level of intervention and aligned with a specific mode of material recovery.

Table 1: Scales of Intervention for Circular Construction Methodologies

Methodology	Scale of Intervention	Primary Focus
Urban Mining	Urban / Building	Identification and quantification of material stocks
Design for Deconstruction (DfD)	Component	Planning for reversibility, disassembly, and future reuse
Recycling	Material	Reprocessing of materials when reuse is no longer feasible

Urban Mining

Urban mining operates at the macro scale, conceptualizing the existing building stock as a latent reserve of anthropogenic materials (Kakkos et al., 2020; Panizza & Nik-Bakht, 2024). It draws on material stock analysis, geospatial mapping, and digital inventories to locate and quantify resources embedded in the built environment. Rather than viewing cities as end points of material consumption, this approach reframes them as dynamic material reservoirs, aligning with circular construction principles. Urban mining is not solely a technical strategy but also a conceptual reorientation of how urban material flows are understood. By treating the city as a system of material latency, it enables urban planning to anticipate and incorporate reuse streams within long-term development strategies. However, its practical implementation remains constrained by fragmented data ecosystems, particularly in non-EU contexts where standardized digital inventories and building-level metadata are often lacking (Nicholson & Miatto, 2024; JRC, 2024).

Design for Deconstruction (DfD)

Design for Deconstruction (DfD) operates at the component scale, emphasizing architectural strategies that enable future disassembly and promote the preservation of material value over time. This approach involves careful consideration of building elements such as walls, cladding, structural systems, and mechanical assemblies. Key principles include modularity, non-destructive joinery, and temporal adaptability, often exemplified through open building systems and reversible construction typologies (Nicholson & Miatto, 2024; Tsikaloudaki, 2025). DfD facilitates the physical separation and reuse of components by prioritizing demountable connections, such as bolts instead of welds, and legible construction methods, thereby extending material life cycles and supporting closed-loop systems.

Theoretically, DfD aligns with architectural concepts of indeterminacy and flexibility, rejecting permanence in favor of transformation and adaptation. As Tsikaloudaki (2025) emphasizes, in line with the Buildings as Material Banks (BAMB) research project's interpretation, "disassembly, adaptability, and reuse form the nucleus of building reversibility," positioning buildings as dynamic repositories of future material resources. Despite increasing academic and policy-level attention, the practical application of DfD remains limited. Barriers include the dominance of conventional construction paradigms, absence of regulatory support, and limited market mechanisms for reused components (Nicholson & Miatto, 2024; Tleuken et al., 2024). Additionally, most existing metrics for DfD evaluation are fragmented across disciplines and remain qualitative, hindering efforts to establish standardized frameworks or cross-sectoral uptake (Tleuken et al., 2024).

Recycling

Recycling operates at the material scale, focusing on transforming end-of-life building elements—such as concrete, brick, steel, and wood—into new material cycles. While it is often considered the least preferable option in circular hierarchies due to risks of downcycling and energy intensiveness, it remains essential where reuse or disassembly is unfeasible (Geissdoerfer et al., 2017).

Recycling is typically assessed through Life Cycle Assessment (LCA) and Material Flow Analysis (MFA), which quantify embodied energy, environmental impacts, and material recovery rates (Icibaci, 2019; Calkins, 2009). However, recycling faces limitations, especially concerning material traceability, which hinders reintegration into high-value applications. As Pineda-Martos et al. (2025) highlight, closed-loop systems benefit from transparency and traceability, enabling informed decision-making about material selection and recycling processes.

INTERPLAY OF SCALES

While urban mining, design for deconstruction (DfD), and recycling each operate at distinct spatial and methodological levels, their combined application offers a powerful framework for systemic circularity. Rather than acting as discrete processes, these methodologies can be structured hierarchically and functionally interlinked, forming a feedback-rich ecosystem of material recovery.

From Inventory to Integration

Urban mining serves as the entry point in this system by identifying material stocks embedded in the urban fabric. Its outputs—comprehensive inventories, GIS-based mapping, and stock classification—offer essential data for anticipating reuse potential at the component level (Panizza & Nik-Bakht, 2024; Brunner & Rechberger, 2004). These data directly feed into DfD strategies, which operationalize circularity by ensuring that materials mapped at the urban scale can later be retrieved without compromising structural integrity.

DfD, in turn, prepares the built environment for future disassembly, reducing contamination and enhancing the purity of material streams. This increases the feasibility of high-quality recycling and reduces the need for downcycling. The logic is cumulative: recycling benefits from DfD-compliant structures, which in turn benefit from data derived from urban mining activities. Each method amplifies the effectiveness of the next in a cascading relationship.

Feedback Loops and Circular Dynamics

This interdependency forms a closed-loop system characterized by both vertical integration (across scales) and lateral feedback (across methods). For example:

- Recycling feedback informs material degradation assessments, which influence DfD design decisions and material selection.
- DfD implementation enhances traceability, supporting more accurate urban mining inventories and long-term material databases.
- Urban mining data becomes richer and more actionable when buildings are DfD-enabled, and materials retain identification tags and metadata throughout their life cycles.

This dynamic reflects a paradigm shift in architectural and urban planning—from single-use building logics to multi-scalar strategies focused on reuse, transformation, and reintegration.

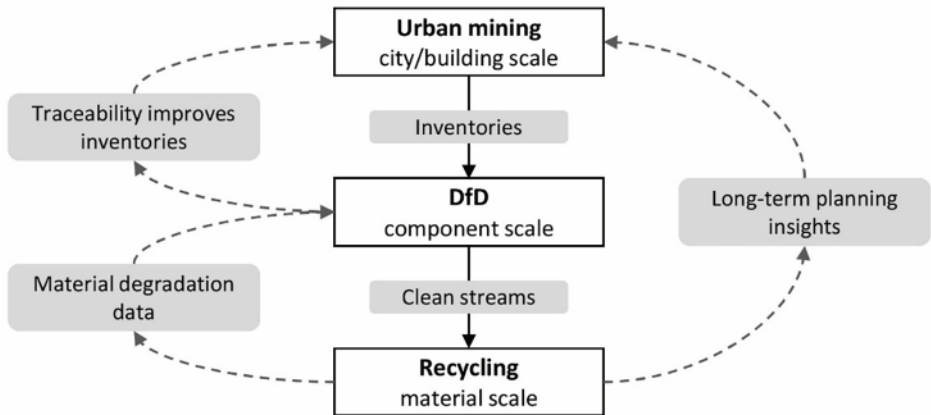


Figure 1: Interplay of Scales in Circular Construction: Urban Mining, Design for Deconstruction, and Recycling as a Systemic Framework. Solid arrows denote hierarchical material flow; dashed arrows indicate feedback loops.

Policy Relevance

The interaction between urban mining, design for deconstruction (DfD), and recycling aligns with the whole-life-cycle perspective promoted by the EPBD 2024, which positions buildings as material banks (European Union, 2024). However, while the directive emphasizes lifecycle carbon and energy performance, it falls short of providing detailed guidance for material recovery infrastructures, especially in non-EU contexts (JRC, 2020; BPIE, 2021). A robust methodological framework, such as the one proposed here, can bridge this gap by operationalizing these policy goals through design and inventory systems, providing the necessary structure for effective implementation of circular strategies at both urban and architectural scales.

DISCUSSION: METHODOLOGICAL SYNERGIES AND CHALLENGES

The three strategies—urban mining, design for deconstruction (DfD), and recycling—exhibit complementary characteristics and are united by their grounding in life cycle thinking, circularity principles, and systemic integration. Their integration offers a powerful framework for systemic circularity, where each methodology strengthens the effectiveness of the others.

Synergies and Conceptual Integration

The strength of urban mining, DfD, and recycling lies in their integrated application. Urban mining provides essential data on material stocks, enabling future-oriented planning and informing DfD design (Panizza & Nik-Bakht, 2024). This data helps structure reversible systems in DfD, preserving material integrity for reuse.

DfD enhances traceability and material purity, crucial for high-quality recycling. Without modular design and disassembly strategies, many materials become inaccessible or contaminated, underscoring the need for integrated material planning (Calkins, 2009).

Recycling, though often a fallback, provides valuable feedback on material degradation and energy use, informing both future DfD designs and urban mining practices. In this way, recycling plays an upstream role, closing the loop in material flows.

Methodological and Structural Challenges

Despite their conceptual alignment, urban mining, DfD, and recycling face significant implementation challenges. Urban mining is constrained by fragmented data ecosystems, particularly in non-EU regions, where cities lack comprehensive material inventories, classification systems, and regulatory frameworks for digital material passports. This impedes its ability to scale and inform resource recovery at the urban level (Brunner & Rechberger, 2004; JRC, 2020).

DfD encounters resistance from traditional construction practices that prioritize speed and cost-efficiency over modularity and reversibility. The lack of standardized evaluation tools and policy incentives further complicates its adoption (Nemeth et al., 2022).

Recycling, although advanced, frequently results in downcycling, particularly for concrete and masonry. In the absence of robust certification and lifecycle tracking systems, recycled materials often fall short of performance standards. Current life cycle assessment models also neglect material reuse histories, limiting their accuracy in evaluating the environmental impact of circular strategies (Icibaci, 2019; Calkins, 2009).

These barriers underscore the need for improved data systems, standardized methodologies, and stronger regulatory frameworks to maximize the potential of circular practices.

LIMITATIONS AND FUTURE RESEARCH

This paper presents a conceptual framework connecting urban mining, DfD, and recycling as strategies for circular construction. However, the study remains theoretical, lacking empirical data or real-world scenario modelling to validate these methodologies. A key limitation is the absence of case-based evidence to demonstrate how these strategies perform under varying urban, regulatory, and material conditions.

Future research should focus on applied studies to explore the operation of integrated digital inventories, modular construction, and traceable material flows in practice. Pilot projects assessing circular workflows and regional adaptations, especially in non-EU contexts, are needed. Exploring informal reuse networks and post-industrial landscapes could also enhance the framework's applicability.

This paper lays the foundation for interdisciplinary research that links architecture, material science, and policy to develop sustainable construction models.

CONCLUSIONS

Urban mining, design for deconstruction (DfD), and recycling form an integrated system for advancing circularity in construction. These interrelated methodologies, operating across urban, component, and material scales, facilitate the transition from linear construction to a circular model grounded in material retention, reversibility, and systemic reuse.

Urban mining identifies and quantifies material stocks, while DfD ensures disassembly and component recovery with retained integrity. Recycling, positioned at the end of the material life cycle, provides feedback on degradation, energy use, and performance, informing both design and planning.

This integrated framework aligns with policies such as the EPBD 2024 and the Circular Economy Action Plan, though challenges remain, particularly in regions lacking digital infrastructure and policy support. Addressing these gaps requires cross-sector collaboration, standardization, and regionally tailored approaches.

This paper contributes to interdisciplinary research linking architecture, material science, and policy, advocating for operationalizing circular strategies in the built environment. Buildings, in this context,

evolve from static end-products to dynamic repositories of value—designed for transformation, dis-assembly, and reintegration.

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