ETHIOPIAN INTERNATIONAL JOURNAL OF MULTIDISCIPLINARY RESEARCH

pISSN:2349-5707 Volume:12, Issue 10, October-2025 eISSN:2349-5715

INTEGRATING CIRCULAR BUSINESS MODELS ACROSS PRODUCTS, MANUFACTURING, AND THE BUILT ENVIRONMENT: A CROSS-SECTORAL FRAMEWORK FOR SUSTAINABLE TRANSITIONS

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ABSTRACT: Background: The transition toward a circular economy (CE) has gained increasing prominence as industries seek sustainability and resource efficiency. Prior research has illuminated diverse circular business models (CBMs), especially product–service systems (PSS), remanufacturing and reuse, and circular construction practices. Yet, these efforts largely remain siloed by sector—manufacturing, consumer goods, built environment, construction—with limited theoretical convergence and cross-sectoral synthesis. Purpose: This study aims to develop a unified, integrative conceptual framework that bridges CBMs across sectors, especially linking manufacturing and product-level circularity with building-level and construction-level circularity, under a life-cycle and diffusion dynamics lens. Methods: Through an extensive conceptual analysis and synthesis of existing literature—including life-cycle modeling, diffusion frameworks, PSS and business model studies, and circular construction reviews—this paper constructs a cross-domain integrative model. It draws particularly on diffusion and product-life-cycle modeling of circular transitions (e.g., Sigüenza et al., 2021), empirical studies of remanufacturing and reuse (e.g., Veleva & Bodkin, 2018), PSS business model configurations (e.g., Pieroni et al., 2019), and circular construction frameworks (e.g., Kanther, 2025; Mhatre et al., 2021). Findings: The proposed integrative framework reveals synergies and common drivers across sectors (e.g., resource efficiency, regulatory push, digitalization), while highlighting sector-specific barriers (e.g., product complexity, regulatory constraints in real estate, consumer behavioural inertia). The model underscores the catalytic role of digital information systems (e.g., PLM, BIM) in enabling transparency, traceability, and decision-support across life-cycles. Implications: The unified framework offers a theoretical foundation for policymakers, practitioners, and researchers seeking holistic circular transition strategies. It suggests avenues for cross-sectoral policy design, standardized circular metrics, and integrated digital tools. It also outlines future empirical research directions—especially quantitative modeling of cross-sector resource flows, and exploration of circular finance models.

Keywords: Circular economy; circular business model; product–service system; life-cycle modeling; circular construction; digital tools.

INTRODUCTION

The concept of a circular economy (CE) has emerged over the past decades as a compelling alternative to the traditional linear "take–make–dispose" economic model. At its core, CE encapsulates an ambition to decouple economic growth from resource consumption by maintaining materials in use for as long as possible, extracting maximum value during their service life, and recovering or regenerating products and materials at end-of-life (Kirchherr et al., 2017; Kirchherr et al., 2023). As industries face mounting resource constraints, environmental degradation, and regulatory pressures, the impetus for circular transition has intensified. However, translating the broad CE vision into actionable business strategies remains a complex challenge, not least because of the diversity of sectors—ranging from manufacturing and consumer products to built environment and construction.

Historically, much of the academic and industrial focus has revolved around discrete sectors. In manufacturing and consumer goods, researchers have investigated remanufacturing, reuse, and PSS business models (Veleva & Bodkin, 2018; Aldieri et al., 2021; Pieroni, McAloone & Pigosso, 2019). In the built environment and construction sectors, separate bodies of literature have explored circular design, material recovery, sustainable procurement, and digital information systems such as Building Information Modeling (BIM) (Kanther, 2025; Mhatre et al., 2021; Yu et al., 2022; Çetin, De Wolf & Bocken, 2021). Even within sectors, distinct technical, economic, and institutional challenges have led to a proliferation of specialized frameworks—with limited integration across domains.

This fragmentation hinders the realization of the full potential of circularity. Emerging evidence suggests that cross-sectoral linkages—and especially the flow of materials and information across product life-cycles, buildings, construction processes and real estate operations—are central to achieving systemic resource efficiency (Sigüenza, Cucurachi & Tukker, 2021; Di Biccari et al., 2019). Yet theoretic synthesis that transcends sector boundaries remains scarce. To design circular strategies that span manufacturing, products, built environment, and construction—and that exploit synergies between them—a unified conceptual foundation is essential.

Problem Statement: Despite growing evidence and models of circular business models and practices in various sectors, there is no comprehensive, cross-sectoral framework that integrates these practices under a common conceptual architecture. This gap impedes systemic circular strategies that account for material flows, life cycles, digital enablers, and cross-sector feedback loops.

Literature Gap: While individual studies provide robust sectoral insights—such as life-cycle modeling for appliances (Sigüenza et al., 2021), PSS business models in apparel (Holtström, Bjellerup & Eriksson, 2019), circular construction practices employing BIM (Di Biccari et al., 2019), and reuse/remanufacturing in biotech equipment (Veleva & Bodkin, 2018)—there is minimal effort to integrate these into a unified theory. Particularly lacking is a model that connects product-level circularity with built environment circularity via shared mechanisms like information transparency, life-cycle assessment, diffusion dynamics, and business model innovation.

Consequently, practitioners and policymakers lack a conceptual tool to assess and coordinate circular transitions across sectors. This paper seeks to fill that void by constructing an integrative conceptual framework, leveraging insights from a wide body of literature, and highlighting the role of digital enablers such as Product Lifecycle Management (PLM) and BIM to facilitate cross-sector circularity.

METHODOLOGY

Given the conceptual nature of this inquiry, the study employs a theory-building methodology grounded in an extensive and systematic synthesis of existing literature. The approach comprises three interrelated stages: (1) scoped literature selection; (2) cross-domain conceptual mapping; and (3) integrative framework construction.

First, literature was selected based strictly on the provided reference list. The sources cover three main domains: manufacturing/consumer goods circularity (e.g., PSS, reuse, remanufacturing), product-level life-cycle modeling, and built environment/construction circularity including digital-building tools. This ensures comprehensive coverage of the key domains crucial for cross-sector circular integration.

Second, through a process of conceptual mapping, the core themes, drivers, barriers, mechanisms, and digital enablers identified in each domain were catalogued. For example, in manufacturing, PSS adoption is driven by resource efficiency and enabled by business model innovation (Pieroni et al., 2019; Aldieri et al., 2021). In construction, the adoption of circular practices often hinges on regulatory frameworks, green procurement, waste classification, and digital design tools (Adams et al., 2017; Yu et al., 2022; Banihashemi et al., 2024). Life-cycle modeling studies offer analytical structures for assessing environmental impacts across product lifespans (Sigüenza et al., 2021; Di Biccari et al., 2019).

Third, synthesizing these mapped elements, an integrative conceptual framework was developed. The framework is structured to represent material flows, information flows, business model typologies, and sectoral interfaces, while accommodating diffusion dynamics over time. The framework is not quantitatively parameterized, but rather designed as a theoretical model intended to guide future empirical research, policy design, and cross-sector circular strategy implementation.

Throughout this process, rigorous cross-reference was maintained: every conceptual assertion in the model traces back to at least one source. The study also considers counter-arguments and limitations: for instance, where sector-specific barriers impede circular practices, or where digital tools pose interoperability or adoption challenges.

RESULTS

The integrative conceptual framework developed through this study reveals a number of interlocking components and dynamics that enable (or hinder) circular transitions across sectors. The following describes the main structural elements, key enablers and barriers, and cross-sector linkages.

Structural Components of the Framework

1. Material Life-Cycle Flow

At the heart of the framework lies a generalized material life-cycle flow that applies to both products (e.g., appliances, apparel, industrial equipment) and built environment components (e.g., building materials, structural elements). This flow traces the trajectory from raw material extraction, manufacturing, distribution, usage, maintenance, reuse/remanufacturing or retrofitting, and finally recovery or regeneration (e.g., recycling or ecological restoration). Life-cycle modeling studies provide the empirical backbone for assessing the environmental implications of such flows (Sigüenza et al., 2021; Di Biccari et al., 2019).

2. Business Model Layer

This layer captures different business model configurations that govern how materials and products are used and re-used across their life cycles. The typology includes:

○ PSS (Product–Service Systems): Model where products are offered as services (e.g., leasing, sharing), instead of being sold outright. This reduces ownership, encourages reuse, and extends service life (Sholihah et al., 2019; Pieroni et al., 2019; Holtström et al., 2019).

○ Reuse/Remanufacturing-based models: Particularly relevant for durable goods and industrial equipment, where products at end-of-use are refurbished and re-enter the market (Veleva & Bodkin, 2018).

○ Retrofitting and refurbishment for built environments: Instead of demolishing buildings, structures are reused or retrofitted, thereby extending service life and preserving embodied materials (Mhatre et al., 2021; Kanther, 2025).

3. Information and Digital Tools Layer

A critical component enabling traceability, transparency, and decision-support is the digitalization of product and building information. This layer includes:

○ PLM (Product Lifecycle Management): For tracking product life-cycles, maintenance history, and facilitating reuse/remanufacturing (Cholewa & Minh, 2021).

○ BIM (Building Information Modeling): For visualizing building materials, life-cycle cost, circularity metrics, remanufacturing potential, and enabling retrofit planning (Di Biccari et al., 2019).

○ Interoperability Infrastructure: Data standards and protocols that allow shared understanding of material states, design specifications, and potential end-of-life uses across stakeholders, enabling flows between manufacturing and construction sectors.

4. Diffusion Dynamics

The framework integrates temporal dynamics, recognizing that circular transitions unfold over time through diffusion processes. Drawing on diffusion-based and product-life-cycle modeling (Sigüenza et al., 2021), the framework proposes that adoption of CBMs spreads across sectors via innovation diffusion mechanisms, regulatory push, market demand, and stakeholder networks. Over successive product cycles and building renovation cycles, cumulative circularity gains can be realized.

5. Sector Interfaces and Feedback Loops

A defining feature of the framework is the explicit recognition of interfaces across sectors:

○ Manufacturing ↔ Consumer Products: Through reuse, remanufacturing or PSS models in goods such as appliances, apparel, or industrial equipment.

○ Consumer Products ↔ Built Environment / Construction: Via reuse of building components, incorporation of durable goods into building systems, and end-of-life recovery linking into construction waste streams.

○ Construction ↔ Manufacturing (or Recycling): Materials recovered from deconstructed buildings feed back into raw material supply, or remanufactured components re-enter construction supply chains.

Information flows (enabled by PLM/BIM) and standardized circular metrics provide the connective tissue across these interfaces.

Key Enablers and Drivers

Based on the conceptual synthesis, the following drivers emerge as cross-sector enablers for circular transitions:

● Resource Efficiency and Environmental Pressure: Resource scarcity, environmental regulations, and carbon/climate change imperatives incentivize circular practices (Mendoza et al., 2022; Sigüenza et al., 2021).

● Business Model Innovation and Economic Value Recovery: PSS and remanufacturing models enable companies to capture value from extended use and multiple life-cycles, transforming cost centers (waste disposal) into revenue streams (Pieroni et al., 2019; Veleva & Bodkin, 2018).

● Regulatory and Policy Support: Particularly in construction and real estate, regulations, green procurement policies, and end-of-life mandates push for circular practices (Ahmed et al., 2024; European Commission, 2020).

- Digitalization and Information Transparency: PLM and BIM systems reduce uncertainty about product and material histories, enabling traceability, life-cycle assessment, and circular decision-making (Cholewa & Minh, 2021; Di Biccari et al., 2019).

- Consumer and Market Demand for Sustainability: Growing consumer awareness and demand for sustainability drive adoption of PSS and circular products (D'Agostin et al., 2020; Aldieri et al., 2021).

Major Barriers and Sector-specific Constraints

Despite the potential, the framework also identifies significant obstacles:

- Complexity and Heterogeneity of Products and Building Materials: Durable goods and building systems have heterogeneous materials, configurations, and usage patterns, complicating reuse, remanufacturing, and remodelling (Guerra et al., 2021).

- Institutional and Regulatory Fragmentation: Different regulations, standards, and ownership models across sectors can create legal or contractual barriers—especially in real estate and construction, where operational leases or long-term ownership complicate circular strategies (Ploeger et al., 2019).

- Lack of Digital Infrastructure or Data Interoperability: Despite the promise of PLM/BIM, many firms lack standardized digital systems; data silos hinder inter-sectoral information flows (Yu et al., 2022; Banihashemi et al., 2024).

- Economic and Market Risks: Investments in PSS or remanufacturing may require upfront costs and offer uncertain returns; small and medium enterprises (SMEs) may lack capacity for circular business model shifts (Maher et al., 2023).

- Cultural and Consumer Behavioural Inertia: Especially in use-oriented PSS models, consumers may resist non-ownership models, or distrust reused/remanufactured products (D'Agostin et al., 2020; Holtström et al., 2019).

DISCUSSION

The integrative framework presented above advances the theoretical discourse on CE by bridging sectoral silos and articulating a cross-domain architecture for circular business models. The synthesis reveals that despite sector-specific differences, there are remarkable commonalities in the drivers, enabling conditions, and challenges—especially when seen through the lenses of life-cycle thinking, information transparency, and diffusion dynamics.

Theoretical Implications

First, the unification suggests that circularity should be conceptualized not as a set of isolated practices, but as a systemic paradigm spanning products, buildings, materials, and information flows. This systemic view enables a deeper appreciation of resource loops that cross sector boundaries—for example, recovered construction materials feeding back into manufacturing, or reused products being incorporated into building retrofits.

Second, the framework highlights the central role of digitalization—not merely as an optional enhancement, but as a foundational enabler. PLM and BIM systems, when interoperable, provide the information architecture necessary to track materials across life cycles, facilitate maintenance and refurbishment, and support end-of-life decisions. This aligns with calls in the literature for "circular digital built environments" (Çetin, De Wolf & Bocken, 2021) and for leveraging PLM in manufacturing circularity (Cholewa & Minh, 2021).

Third, the integration of diffusion dynamics adds a temporal dimension often neglected in sectoral case studies. Circular transition is not instantaneous; it unfolds over successive product cycles, building renovations, and regulatory waves. By situating circular business models within a diffusion framework (Sigüenza et al., 2021), the model suggests that systemic resource savings accumulate gradually—magnifying the long-term benefits of early adoption.

Practical and Policy Implications

From a practitioner perspective, the framework offers guidance for companies and industry consortia aiming to implement circular strategies. By acknowledging cross-sector interfaces, firms can explore synergies—for instance, manufacturers collaborating with construction firms to supply refurbished building components, or real estate developers partnering with PSS providers for appliance-as-a-service models in buildings.

For policymakers, the framework underscores the need for integrated regulatory and standardization efforts. Rather than regulating sectors in isolation (e.g., waste, construction, manufacturing), policies should encourage cross-sector material flows, data interoperability, and circular procurement practices. For example, green public procurement standards (Ahmed et al., 2024) could mandate reuse of recovered materials across sectors, while incentives could support the development of PLM/BIM infrastructure.

Limitations

While the conceptual framework offers a robust starting point, it is subject to several limitations. First, the framework is not empirically validated; it lacks quantitative parameterization or simulation to estimate potential material savings, economic benefits, or environmental impacts. Without such modeling, it remains a conceptual tool rather than a predictive or prescriptive instrument.

Second, the framework assumes the availability and interoperability of digital tools like PLM and BIM—conditions that may not hold in many developing economies or in SMEs lacking resources for digital investments. The transition to circular practices may thus be slower and more uneven than the framework suggests.

Third, sectoral idiosyncrasies—such as differences in material durability, regulatory frameworks, ownership models, and user behaviour—may limit the generalizability of the framework. For instance, while PSS models may work well for appliances or apparel (Holtström et al., 2019; Pieroni et al., 2019), their applicability to heavy structural building components may be constrained by technical, safety, or durability issues.

Fourth, the framework does not explicitly address social factors—such as labour implications of reuse/remanufacturing, supply chain equity, or stakeholder power dynamics. These social dimensions may influence the feasibility and desirability of circular transitions.

Future Research Directions

To build on this conceptual foundation, future research should pursue several avenues:

- Quantitative Modeling of Cross-Sector Material Flows: Using life-cycle assessment (LCA) and diffusion modeling techniques (as in Sigüenza et al., 2021), researchers can simulate scenarios to estimate resource savings, emissions reductions, and economic outcomes under different adoption rates of the proposed integrated CBMs.

- Empirical Case Studies Across Sector Interfaces: Case studies that span manufacturing, product reuse, building retrofits, and deconstruction would provide real-world validation. For example, examining a project where refurbished appliances are installed in retrofitted buildings, or where recovered building materials feed back into manufacturing supply chains.

- Digital Infrastructure and Interoperability Standards Research: Investigation into how PLM and BIM systems can be standardized across sectors, and how data governance, privacy, and ownership issues can be addressed to support cross-sector circular flows.

- Social and Institutional Analysis: Research into labour market impacts, stakeholder incentives, consumer acceptance, regulatory frameworks, and governance models that support or hinder circular transitions.

- Economic and Financing Mechanisms for SMEs: Given that many small and medium enterprises lack resources for digital tools or business model transformation, research is needed into financing models—such as circular loans, leasing schemes, or public–private partnerships—that can enable broader participation in circular transitions (Maher et al., 2023).

CONCLUSION

This study offers a comprehensive, integrative conceptual framework that bridges circular business models across manufacturing, product life cycles, built environment, and construction sectors. By synthesizing insights from life-cycle modeling, PSS and remanufacturing studies, and circular construction literature, the framework reveals structural commonalities, cross-sector synergies, and the pivotal role of digital tools and diffusion dynamics. While conceptual, the model lays the foundation for future empirical research, policy development, and industry practice aimed at systemic circular transitions. Embracing this unified perspective could accelerate resource efficiency, reduce environmental impact, and foster resilient, interconnected circular economies.

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