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Circular Economy Pathways in the U.S. Building Sector: Advancing Sustainable Materials and Construction Waste Reduction

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Abstract: U.S. construction industry is one of the largest contributors to resource depletion and generation of waste, with almost 40 percent of total material use and solid waste. The principles of the circular economy (CE) that focus on the reduction, reuse, and recycling of materials provide a transformative scheme for attaining sustainability in the building industry. This narrative review summarized the recent developments, policy frameworks, and technological developments that led to the circular construction practices in the United States. It critically analyses current material recovery, design to deconstruct, and industrial symbiosis approaches, points of knowledge gap and new research frontiers. The databases analyzed to analyze peer-reviewed studies included Scopus, Web of Science, and ScienceDirect (published in the last 5 years 2020-2025). The review has given a priority to literature that is U.S.-based that combines the concept of Circular Economy in producing materials, waste management and design of green buildings. The new tendencies show an increasing correspondence between the CE implementation and the federal sustainability targets, where the innovation clusters are recycled concrete, modular construction, and lifecycle design. The problem is however, hindered by policies and fragmentation, lack of standardization of data, and economic obstacle. To reach a real U.S. building sector that is circular, there will be the need to unify policies, measure lifecycle, and make cross-sectoral efforts to close material loops and achieve reduced embodied carbon to hasten the transition to net-zero construction.

Keywords: Circular economy, Construction waste reduction, Sustainable materials, Building sector, Life cycle assessment.

INTRODUCTION

The United States construction industry is experiencing a serious reckoning with the effect it has on the environment. According to the current data, the U.S. building industry is responsible for almost a quarter of the total energy expenditure in the country and an estimated third of all solid waste produced every year, mainly due to construction and demolition (C&D) activity (EPA, 2022). Historical linear approaches to material use, i.e. extraction, use, and disposal of resources, have resulted in significant ecological degradation, resource depletion and greenhouse gas emissions (Hossain *et al.*, 2020; Pomponi & Moncaster, 2021). The notion of the circular economy (CE) has thus become a mainstream concept as an option to decouple economic growth and environmental degradation (Geissdoerfer *et al.*, 2020; Norouzi *et al.*, 2021). The built environment approach of CE puts emphasis on the material efficiency, reduction of waste, and regenerative design (Ogunmakinde *et al.*, 2022).

Geissdoerfer *et al.*, (2020) define a circular economy as an industrial system that is regenerative and restorative in nature and strives to ensure that products, components, and materials remain in their optimal utility and highest value at all times. The importance of this subject matter is that it could change the way the building sector operates: the implementation of the principles of a circular economy into the building industry could greatly minimize environmental footprints, increase the life cycle of the materials, and trigger the economic growth of the green economy. Considering the ambitious climate targets and initiatives of the federal government, such as the Inflation Reduction Act (2022) and net-zero carbon by 2050, the reconsideration of material use in buildings is urgent (White House, 2021; U.S. Congress, 2022). The circular construction practices are also in line with the United Nations Sustainable Development Goals (SDGs), particularly SDG 11 (Sustainable Cities and Communities) and SDG 12 (Responsible Consumption and Production) (Ogunmakinde *et al.*, 2022; United Nations, 2023).

The recent peer-reviewed literature highlights the contemporary developments and ongoing challenges of the further development of CE in the U.S. building industry. To exemplify, a study conducted by Pomponi and Moncaster (2021) identifies the slow pace of material reuse protocols adoption because of regulatory and market barriers. In the meantime, Ghaffar *et al.*, (2023) report favorable changes in bio-based construction materials and digital solutions like Building Information Modeling (BIM) combined with material passports. Even with these developments, Reike *et al.*, (2022) have mentioned that standardized measures of CE performance in construction projects are lacking. Additionally, the

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literature reveals the presence of systemic fragmentation in the presence of supply chains as well as the lack of scalable infrastructure in the context of reverse logistics and material recovery.

The research gap is therefore complex: although the CE theory is highly developed, practical implementation of the theory in the U.S. construction business is still biased and disorganized. It is urgently necessary to integrate existing experience of what is possible, where, and why, based on learning from success stories, as well as regions of failure. This narrative review fills that gap by offering a professional-based account of emerging trends, key obstacles, and new approaches to CE implementation in the U.S. building industry.

This review is aimed at investigating the operationalization of the principles of the circular economy in the U.S. building industry with a particular emphasis on sustainable materials and construction waste elimination. Instead of having a comprehensive systematic overview, this paper interprets emerging trends, integrates significant discoveries, and finds practical implications to the researcher, policymakers, and practitioners. The review by highlighting the innovative initiatives and the ongoing challenges, will map a path toward the speedy phase of the circular transformation of the built environment in the United States.

EMERGING TRENDS AND THEMATIC ANALYSIS.

Material Innovation and Bio-Based Alternatives

The construction industry is experiencing an influx of innovative materials that consider the principles of the circular economy, such as bio-based and recycled-content materials. Hempcrete, cross-laminated timber, mycelium composite, and reclaimed brick or concrete are being welcomed due to their low embodied carbon and renewable or re-use (Benachio *et al.*, 2020). Ghaffar *et al.*, (2023) reported developments in biodegradable composites and agro-waste-based insulation panels, which display the potential of scaling with insignificant environmental effects. Everyday adoption is, however, hampered by costs, absence of performance testing criteria, and regulatory reluctance. Other works, such as Yu *et al.*, (2021), indicate that governments should have testing guidelines and green procurement incentives to popularize these materials in construction.

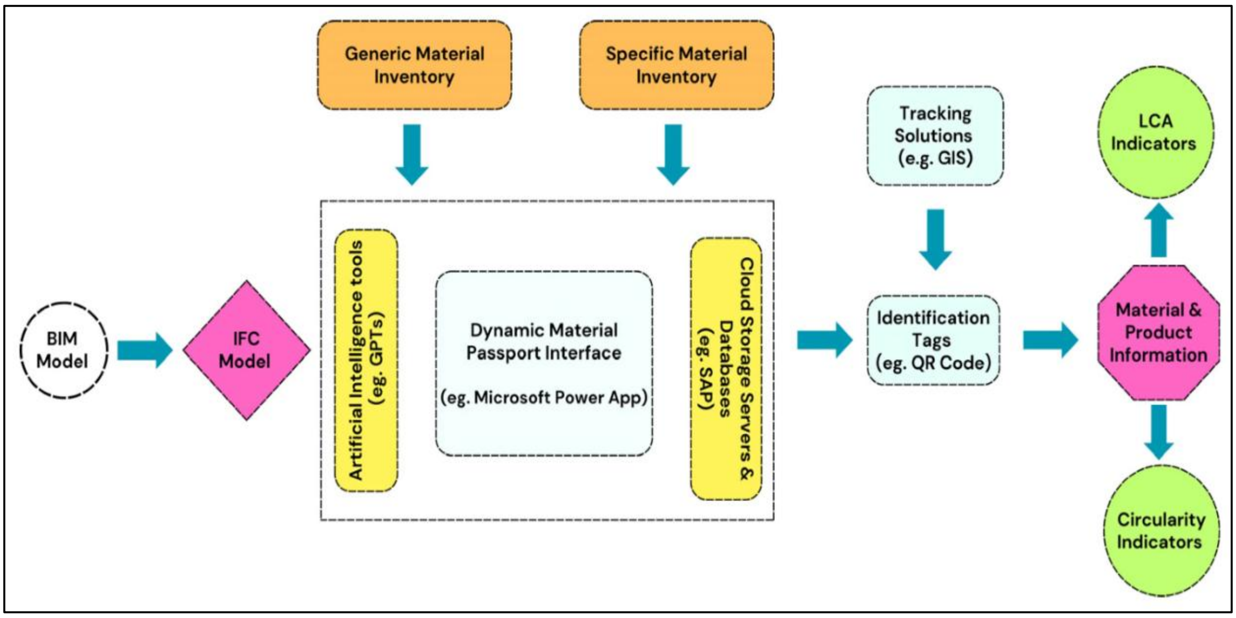

Fig:1 Markou, I.; Sinnott, D.; Thomas, K. Current Methodologies of Creating Material Passports: A Systematic Literature Review. *Case Stud. Constr. Mater.* 2025, *22*, e04267.

Tools of Digitalization and Circular Design.

With digital transformation, the implementation of CE strategies is becoming more effective with the use of such tools as Building Information Modeling (BIM), material passports, and digital twins. The lifecycle tracking and disaster analysis workflows of reuse and recycling are better facilitated by BIM-integrated CE workflows that are designed to assist in disassembly and scenario analysis. As Akinade *et al.*, (2021) revealed, when deconstruction planning is incorporated in the BIM workflow, the process of material recovery and

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predictability of the project is enhanced. Material passport (which is currently being piloted in pilot projects, EPA, 2022) is a method to improve the transparency and future-proofing of buildings, where information on the specific components is recorded to be recovered at the end of their life. However, the problem of interoperability between software systems and the absence of standardized data format are still hurdles (Çetin *et al.,* 2023; Coskun *et al.,* 2022).

U.S. Policy and Regulatory Environment.
The policy environment in the U.S. is slowly changing towards acceptance of CE practices, although not uniformly across all states. The Buy Clean Initiative and the Inflation Reduction Act (2022) are just a few examples of federal measures that have implemented the low-carbon materials requirement and investment in sustainable infrastructure. On the state front, California and Washington have the highest levels of green building requirements that incorporate the requirements of circularity (California Air Resources Board, 2022). EU (2024) compares a regional policy and concludes that the extended producer responsibility (EPR) and deconstruction ordinance can greatly boost the results of the circle. Nevertheless, the absence of national CE law and the disjointed implementation are counterproductive to the unity of progress. Researchers note that it is necessary to integrate regulatory systems and implement credits or taxes on the reuse of materials (Hossain *et al.,* 2020).

Implementation and Industry Perception: Potential Barriers to Implementation.
Nevertheless, there are still practical and psychological obstacles, even with the increasing momentum. The cost premiums, the increased project completion time and the insurance premiums that are connected with unconventional materials or reusing materials are often mentioned by construction companies (Cruz Rios *et al.*, 2021; Ogunmakinde *et al.,* 2022). According to the AIA (2023) survey, the confidence in the performance of reclaimed materials is low, even though case studies have shown the contrary. The logistics of material recovery and reuse is also complicated by the discontinuous character of the construction supply chain (Bilal *et al.,* 2020; Munaro & Tavares, 2023). The development of public-private partnerships, as well as demonstration projects, is required to de-risk adoption and give definitive evidence on the economic viability of CE (Finamore & Oltean-Dumbrava, 2024). Architectural, engineering, and contracting education and training are also needed to effect cultural change in the industry (Charef & Emmitt, 2021).

Table 1. Summary of Key Findings on Circular Economy Practices in the U.S. Building Sector

Thematic Area	**Key Findings**	**Evidence from Literature (2020–present)**	**Implications for Practice & Policy**
Environmental Impact of Linear Construction	Linear material-use models dominate the U.S. construction sector, resulting in high energy consumption, substantial C&D waste, and elevated greenhouse gas emissions.	EPA (2022); Hossain *et al.,* (2020); Pomponi & Moncaster (2021)	Reinforces the urgency of transitioning away from linear models toward circular material flows.
Circular Economy as a Transformative Framework	CE offers a systems-based pathway to decouple economic growth from environmental degradation through reuse, recycling, and regenerative design.	Geissdoerfer *et al.,* (2020); Norouzi *et al.,* (2021)	Positions CE as a strategic framework rather than a niche sustainability practice.
Sustainable and Bio-Based Materials	Bio-based and recycled-content materials (e.g., hempcrete, CLT, mycelium, recycled aggregates) show strong potential for reducing embodied carbon but lack long-term field validation.	Benachio et al. (2020); Le *et al.,* (2023); Pomponi & Moncaster (2021)	Calls for longitudinal performance studies and integration into building codes and insurance frameworks.
Digital Tools and Circular Design	BIM, material passports, and digital twins improve lifecycle	Akinade *et al.,* (2021); Charef & Emmitt	Highlights the need for standardized data

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	tracking, design-for-disassembly, and material recovery planning; however, interoperability issues persist.	(2021); Munaro & Tavares (2021); Çetin et al. (2023)	formats and digital governance frameworks.
Policy and Regulatory Landscape	Federal initiatives (IRA, Buy Clean) support low-carbon materials, while state-level adoption of CE practices is uneven; no unified national CE framework exists.	U.S. Congress (2022); GSA (2023); Zu Castell-Rüdenhausen *et al.*, (2021)	Indicates the importance of harmonized policies, incentives, and national CE standards.
Reverse Logistics and Reuse Markets	Material recovery infrastructure and reuse markets are underdeveloped; economic viability and pricing mechanisms remain poorly understood in the U.S. context.	Cruz Rios *et al.*, (2021); Mohammadiziazi & Bilec (2022)	Suggests the need for regional reuse hubs and economic modeling of reverse logistics systems.
Industry Perception and Behavioral Barriers	Cost premiums, liability concerns, and low confidence in reclaimed materials persist despite positive case evidence.	Ogunmakinde *et al.*, (2022); AIA (2023); Bilal *et al.*, (2020)	Emphasizes the role of education, demonstration projects, and risk-sharing mechanisms.
Performance Measurement and Metrics	No consensus exists on appropriate CE performance indicators (e.g., waste diversion, carbon savings, circularity indices).	Reike *et al.*, (2022); Khadim et al. (2022)	Demonstrates the need for standardized, multi-dimensional CE assessment frameworks.
Global vs. Local Circularity Strategies	Tension exists between globalized supply chains and localized reuse strategies, requiring context-specific CE models.	Sparrevik *et al.*, (2021); Mohammadiziazi & Bilec (2023)	Supports the development of regionally adaptive CE strategies balancing efficiency and resilience.

TECHNOLOGICAL, ETHICAL, AND TRANSLATIONAL CHALLENGES

The interoperability and data governance have technological issues. BIM, material passports, and digital twins present a challenge under the interoperability, privacy, and ownership of data. The future research should be on how the information stored in CE can be stored, who has access to it and how long-term digital archives can be sustained when there is a series of shifts in ownership of the building.

With the growing material reuse, ethical concerns arise of safety, liability, and non-equity access. To illustrate, reused materials can be distributed unequally to low-income communities because it is cheaper. Researchers need to investigate the way of making sure that CE strategies avoid contributing to environmental injustice unintentionally.

The issue of the disconnect between innovative scholarly research and practice remains a consistent problem. Contractors have very few incentives or training to use models or materials even when they are validated; this is because of the barriers in translation between research and practice. Translational research is required to transform anything theorized in the CE frameworks into toolkits, guidelines, and scalable business models.

As CE is on its way to transforming the construction workflows, there is a significant gap in training. The studies that are required are the way to incorporate CE principles into the engineering, architecture, and construction management courses and how to reskill the current workforce to operate in deconstruction, reuse logistics, and digital tools of CE.

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Lack of Standardized Metrics for Circularity Assessment

Although the research on the CE-related construction studies has dramatically increased, the lack of common performance indicators is a significant research gap. The current metrics are diverse, and different studies may have different measures of what is diverted or saved in embodied carbon, so that cross-study comparisons may not be effective. According to such scholars as Reike *et al.*, (2022), a national assessment system of the CE needs to be developed exclusively within the U.S. building industry. The gap prompts a significant question: What is measurable and comparable circularity in the varied types of buildings and the regional contexts?

The use of bio-based and reused building materials has a future, although the majority of investigations are based on temporary laboratory experiments. There are very few long-term field tests to confirm durability, weather resistance or lifecycle carbon performance in real-life conditions (Le *et al.*, 2023; Benachio *et al.*, 2020). This restricts the trust of the stakeholders in the adoption of reclaimed materials on a large scale (Pomponi & Moncaster, 2021).

Despite the central role of material recovery infrastructure, the literature on U.S. reverse logistics systems is very small and divided. The empirical investigation of the local markets of reuse functioning, the development of pricing structure, and the economic incentives that have a significant impact on the contractor behavior is under-researched (Cruz Rios *et al.*, 2021; Mohammadiziazi & Bilec, 2022).

The cultural, perception, and institutional norms factors play a role in CE adoption has not been adequately investigated. The studies concentrate more on technical or policy issues and leave questions like: How do risk perceptions influence the decisions of architects and contractors? Which educational interventions can change the industry attitudes towards CE?

FUTURE RESEARCH DIRECTIONS

The next step in the concept of the standardized system of scoring of CE, as the LEED or WELD, but this time, with reference to circularity, should be the focus of future research. Researchers would have an opportunity to examine how to incorporate this by adding circularity indicators (material reuse rates), disassembly readiness scores, and circularity index into current green certification frameworks. Such benchmarks should be pilot tested on a variety of building typologies to produce irreplaceable comparative data.

Researchers should increase real-world performance testing to promote material science by using long-term field testing and gain industry confidence in bio-based and reused materials. Innovative materials need to be monitored by field studies of humidity cycling, structural degradation, fire resistance, and end-of-life reclaimability. University-DOTs-green building council partnerships can accommodate projects in long-term monitoring.

It is highly demanded that the circular supply chains have computational models that can be used to simulate the material movements, costs, transportation effects, and carbon savings over the regional CE hubs. Digital twins of urban material ecosystems should be built in the future to assist policymakers in predicting bottlenecks and assessing infrastructure investments.

As a behavioral researcher, an understanding of human factors and decision-making will be necessary to identify how the stakeholders perceive the information, incentives and risks of CE. In the future, mixed-method techniques like surveys, ethnography, and behavioral experiments could be utilized to investigate contractor reactions to reused material pricing or liability sharing contracts or policy nudges.

A policy experiment and comparative policy analysis should also be devised by the researchers to assess the effect of current state-level CE policies in the U.S., including deconstruction ordinances and Buy Clean procurement requirements. Comparative interstate or against the EU CE policy studies may help to identify the most effective and scalable instruments. There is also a research gap on the impact of CE policies on affordability, housing markets, and development of workforce.

CONCLUSION

The transition toward a circular economy (CE) in the U.S. building sector presents both a significant challenge and a major opportunity for systemic transformation. This review synthesizes recent advances in sustainable materials, digital tools, policy frameworks, and industry practices, highlighting a field that is evolving rapidly but remains constrained by structural and institutional barriers. Emerging trends, such as bio-based material innovations and BIM-integrated circular

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design workflows, signal a shift toward resource efficiency, lifecycle-based decision-making, and regenerative design.

The literature indicates that CE adoption is moving beyond theory into practice through pilot projects, policy initiatives, and supply chain innovations. Materials such as hempcrete, cross-laminated timber, and mycelium composites demonstrate the potential of renewable resources to reduce embodied carbon, while digital tools, including material passports and BIM-based deconstruction planning, improve transparency, coordination, and material recovery across building lifecycles. However, progress is uneven. Regulatory fragmentation, underdeveloped reverse logistics infrastructure, limited long-term performance data, and persistent industry scepticism continue to hinder large-scale implementation. A key limitation remains the absence of standardised circularity metrics, which complicates performance evaluation, procurement, and policy alignment.

Looking forward, circularity offers a pathway to systemic change through regional reuse hubs, deconstruction networks, and urban material management strategies. Achieving this transition will require integrated policy frameworks, workforce development, and expanded use of data-driven tools to support scalable, resilient circular construction practices.

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