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Material Inventories and Circular Economy Strategies in Construction – A Literature Synthesis

Amr G. Mansour[1] and Mohammed S. Hashem M. Mehany[1]
[1]Colorado State University

Transitioning the construction industry towards circular economy (CE) requires reliable and interoperable material information systems. Despite growing attention to CE, existing research remains centered on waste management, resulting in fragmented and reactive practices. This paper presents a systematic literature review on the integration of material inventories and CE to promote proactive, data-driven circularity practices in construction. Following PRISMA guidelines, 28 studies were reviewed and included in the final analysis. The paper aims to synthesize existing research on material inventories and CE in construction, explore CE strategies enabled by material inventories, identify the data types used in material inventories, and highlight research gaps and future directions. Findings reveal that material inventories act as key enablers across four CE strategies material reuse, recycling, deconstruction planning, and circularity in design by providing structured information to identify and evaluate materials for recovery and reuse. However, current practices remain largely relying on textual data from audits and reports. This study contributes to the body of knowledge by systematically mapping how material inventories facilitate circularity across different strategies and linking diverse material data types with emerging technologies, while offering practical guidance on improving material data management to support a more sustainable and circular built environment.

Keywords: Circular Economy, Material Inventories, CE Strategies.

Introduction

Global resource scarcity has intensified the urgency to reduce dependence on virgin materials. As one of the world's most resource-intensive sectors, construction accounts for 60% of global raw material extraction (Honic et al., 2019; Benachio et al., 2020) and generates approximately 25% of global solid waste (Benachio et al., 2020). In the United States, construction and demolition (C&D) waste constitutes nearly 65% of total solid waste (Ginga et al., 2020; Chandrappa & Das, 2024). Despite this scale, most buildings are demolished without systematic assessment of materials available for recovery (Benachio et al., 2020; Gontia et al., 2020). This is rooted in the traditional linear economy (LE) model, where materials are extracted, used, and discarded with limited consideration for reuse or recycling (Honic et al., 2019; Wu et al., 2022). Design practices also rarely anticipate deconstruction, contributing further to material loss (Nemeth et al., 2022). In contrast, the circular economy (CE) model has emerged as a transformative framework aimed at extending material lifecycles through reuse, recycling, and design strategies (Gerhardsson et al., 2020; Pešta et al., 2024; Cottafava & Ritzen, 2021). Existing structures approaching end-of-life thus represent valuable material banks

(Guerriero et al., 2024; Honic et al., 2019; Maraqa & Spatari, 2022). Although CE strategies such as reuse, recycling, and deconstruction planning are widely discussed, far less attention has been given to the role of material inventories and how the structured documentation of material type, quantity, condition, and provenance enables these strategies. Limited research has examined what types of data material inventories contain, how these data are generated, and how inventories enable CE implementation in practice. This gap hinders the development of robust material information systems and constrains the adoption of circular practices. To address this gap, this paper conducts a systematic review of literature on material inventories in construction and their role in advancing CE strategies. The study is guided by three objectives: 1) to review the current research on material inventories and CE strategies in the construction industry; 2) to explore data types and sources for establishing material inventories; and 3) to identify research gaps and propose potential future research directions

Research methodology

This paper uses a systematic review method in searching and analyzing relevant literature to meet the research objectives. The review process follows the guidelines set forth by Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). The PRISMA-Protocol guides the development and reporting of systematic review procedures (Pahlevan-Sharif et al., 2019). To find relevant publications, the study utilized two renowned search engines due to their extensive coverage in the fields of construction engineering and management research: Scopus and Web of Science. The search strategy included the following terms ("Circular Economy" OR "Circularity" OR "CE") AND ("Construction material") AND ("Inventory"). The search conducted on January 8, 2025, yielded 110 journal articles and conference papers written in English from both databases. After removing duplicates, 77 articles remained for abstract screening. The abstract screening aimed to identify articles aligned with the research objectives and questions. A total of 49 articles were removed based on the following exclusion criteria: 1) the study did not focus on CE or their applications in construction industry; 2) CE was mentioned only as a recommendation, rather than a primary focus; or 3) the article was a review paper. 28 articles were included and analyzed in this paper.

Figure 1 illustrates the overall methodological framework used in this study, presented in three connected stages. The left section depicts the systematic identification process following PRISMA guidelines, beginning with the initial database search, removal of duplicates, and abstract screening, and concluding with the selection of 28 studies for detailed analysis. This section visualizes how the literature pool was progressively refined to ensure that only publications directly addressing material inventories and circular economy strategies were included.

The center section of the figure shows the thematic analysis phase, which organizes the selected studies into analytical categories based on their contribution to circular economy practices. This stage reflects how the literature was clustered around key CE strategies, such as material reuse, material recycling, deconstruction planning, and circular design as well as around the types of data and data sources used to generate material inventories. Thematically mapping the studies enabled the synthesis of patterns, methodological trends, and emerging technological approaches across literature.

Finally, the right section of the figure summarizes the future research directions derived from this synthesis. It highlights the methodological and technological gaps identified during analysis and outlines the need for more integrated, multimodal, and lifecycle-based approaches to material inventories. Together, the three components of Figure 1 present a comprehensive overview of the study’s methodological flow from systematically identifying relevant literature, to thematically analyzing its contributions, and finally articulating forward-looking research pathways.

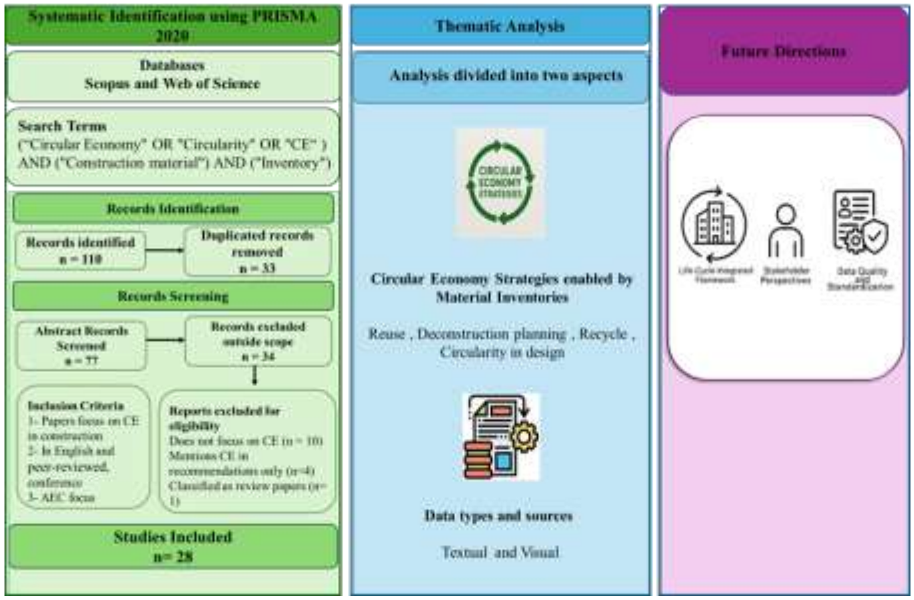

Figure 1. Research Methodology

Thematic Analysis and Data Synthesis

Data synthesis was conducted using Braun and Clarke's thematic analysis framework, adapted for a systematic literature review context (Braun & Clarke, 2006). Following the PRISMA-guided selection of 28 studies, thematic analysis was employed to synthesize and interpret patterns across the literature related to the role of material inventories in enabling CE strategies in construction. This approach enabled a structured examination of how material inventories support different CE strategies and the types of data used to generate such inventories, while also facilitating the identification of research gaps and future directions.

The analysis began with familiarization, in which all included studies were read in full to gain an in-depth understanding of their objectives, methods, and findings. Key information including abstracts, keywords, CE strategies addressed, data types, and technologies used was extracted and organized in Microsoft Excel. Initial coding was then performed manually by the primary author using an inductive approach, allowing codes to emerge directly from the literature rather than being predefined. Codes captured recurring concepts such as material reuse, recycling, deconstruction planning, circular design, textual data sources, visual data sources, and enabling digital technologies.

In the theme development phase, related codes were grouped into broader analytical categories. Studies were iteratively clustered based on their primary CE strategy focus and the nature of the material data employed. Through this process, provisional themes were refined and consolidated until thematic saturation was achieved. The themes were reviewed to ensure internal coherence and clear distinction between categories, with particular attention given to consistency between coded evidence and extracted study attributes. This iterative refinement resulted in two overarching analytical dimensions: (1) CE strategies enabled by material inventories, and (2) data types and sources used to generate material inventories, with subthemes corresponding to material reuse, recycling, deconstruction planning, and circularity in design, as well as textual and visual data sources.

Theme definitions and naming were finalized following repeated cross-checking against the extracted dataset to ensure that each theme was supported by multiple studies and accurately reflected the underlying evidence. To enhance reliability and reduce subjectivity, the evolving coding framework and thematic structure were periodically reviewed in consultation with the co-authors. Themes were refined iteratively based on feedback and repeated cross-checking against the extracted study attributes. The finalized themes were then integrated into the results and discussion sections to structure the synthesis, highlight dominant research trends, and identify underexplored areas within the literature. This transparent and iterative thematic analysis process underpins the study's synthesis and supports the reliability and reproducibility of the findings.

Literature Synthesis and Discussions

The subsequent literature analysis and discussion is structured around two key aspects: (1) CE strategies enabled by material inventories; (2) Data types and sources employed in the generation of these inventories.

CE Strategies Enabled by Material Inventories

Material Reuse

Material reuse is the most extensively examined CE strategy supported by material inventories in the reviewed literature. Through studies, material inventories are consistently positioned as enabling data infrastructures that support reuse-related decision-making at the end-of-life stage of buildings. The literature identifies two main reuse applications: feasibility assessment and forecasting for market alignment. The first and most prevalent application focuses on reuse feasibility assessment, where material inventories are used to identify, document, and evaluate building components suitable for secondary use. In this application, inventories provide structured information on material type, quantity, dimensions, condition, and provenance, which is subsequently integrated with digital tools such as Building Information Modeling (BIM) and Life Cycle Assessment (LCA). Multiple studies demonstrate how inventory-enriched BIM and LCA frameworks enable the evaluation of reuse scenarios by comparing technical and environmental performance against conventional disposal or recycling pathways (Guerriero et al., 2024; Gerhardsson et al., 2020; Pešta et al., 2024). Case-based research further illustrates how inventories documenting material geometry and condition facilitate reuse planning for structural steel and other components (Bennet et al., 2023), while similar assessment-oriented approaches are applied to evaluate reusable polymer-based components through LCA (Bautista et al., 2023). Collectively, these studies converge on a shared conclusion: inventories are a prerequisite for credible reuse assessment, as BIM models alone lack the material-specific attributes required to evaluate reuse potential, and LCA outcomes depend heavily on accurate and comprehensive inventory data. Despite this methodological maturity, assessment-oriented research remains largely reactive, emphasizing evaluation once buildings reach end of life (EoL).

A second, less-developed application extends material inventories toward reuse forecasting and market alignment. In contrast to static assessment models, these studies conceptualize inventories as dynamic datasets capable of supporting supply–demand coordination in secondary material markets. For example, Lin et al. (2024), integrate inventory data with predictive modeling techniques to forecast future material availability and anticipate market demand for reusable components. While this approach directly addresses uncertainty in material supply, forecasting-oriented research remains limited in scope and is largely confined to conceptual or pilot-scale applications.

Across both reuse applications, a key limitation relates to data quality and scalability. Most studies rely on manually collected textual data, limiting automation and introducing uncertainty when scaling reuse beyond individual projects (Pešta et al., 2024; Bennet et al., 2023). Although visual data sources such as drone imagery have been explored (Mager & Blass, 2022; Mahmudnejad et al., 2023), these efforts remain fragmented and are discussed separately. Overall, material reuse literature shows strong analytical depth in feasibility assessment but exposes gaps in proactive planning, market integration, and scalable data infrastructures, underscoring the need for interoperable, lifecycle-aware inventory systems. While reuse focuses on evaluating existing components, subsequent CE strategies shift attention to how materials are dismantled and processed at end-of-life.

Deconstruction planning

Deconstruction planning represents a distinct CE strategy in which material inventories are used to support selective dismantling and material recovery at end-of-life (Han et al., 2024). Unlike material reuse or recycling strategies that focus on material evaluation or waste characterization, deconstruction planning centers on determining what to dismantle, in what sequence, and with what recovery intent, with the goal of preserving component integrity for downstream use (Melella et al., 2021).

The dominant body of deconstruction-focused research concentrates on planning and sequencing applications, where inventory data are integrated with digital tools such as BIM and 4D simulation. In these studies, inventories specifying material type, quantity, condition, and spatial location enable simulation of dismantling scenarios, coordination of activities, and alignment between recovery objectives and site logistics (Han et al., 2024; Melella et al., 2021). Several studies demonstrate that embedding inventory information within BIM environments enhances visualization and sequencing accuracy, thereby supporting more controlled and recovery-focused deconstruction workflows (Andriyani et al., 2024; Han et al., 2024; Melella et al., 2021).

A smaller subset of studies extends inventories toward decision-support and environmental impact evaluation, where alternative deconstruction strategies are compared based on emissions, waste diversion, and recovery outcomes. By coupling inventory data with LCA, these studies move beyond operational planning to assess the broader implications of dismantling choices (Han et al., 2024; Melella et al., 2021). However, such applications remain largely project-specific and are typically applied after deconstruction options have already been defined.

Beyond project-level applications, the literature suggests that broader adoption of deconstruction planning requires supportive policy and standardization. Mandating the creation and maintenance of material inventories through regulatory frameworks could improve data consistency, interoperability, and transparency, enabling more effective integration with BIM and LCA tools. Such standardization would support real-time decision-making and scalable implementation of deconstruction strategies.

Beyond dismantling and recovery planning, CE strategies also address how recovered materials are processed at scale, which is the focus of material recycling.

Material Recycling

Material recycling of construction and demolition waste (CDW) constitutes a well-established CE strategy in the reviewed literature; however, its treatment differs markedly from reuse and deconstruction planning approaches. Recycling-focused studies primarily conceptualize material inventories as quantification and characterization tools for bulk material flows, rather than as decision-support systems for component recovery or sequencing (Paz et al., 2023; Cuenca-Moyano et al., 2019). As a result, the analytical emphasis shifts from component integrity to material volume, composition, and process efficiency.

Across literature, two dominant and distinct research clusters emerge. The first cluster focuses on recycled aggregate (RA) production (Cuenca-Moyano et al., 2019), where material inventories are used to identify suitable CDW streams and estimate quantities available for processing. Studies in this cluster consistently demonstrate that accurate inventory data enables substitution of virgin aggregates with recycled fine aggregates (RFA), particularly in masonry mortars, thereby reducing environmental impacts. Regulatory permissibility under European Standard EN 13139 further supports this application, as it allows the unrestricted use of recycled aggregates in mortars (Cuenca-Moyano et al., 2019). Given that masonry mortar consists of approximately 90% aggregates by volume, these studies emphasize volume certainty as the primary condition for effective recycling, distinguishing recycling from reuse strategies that depend on component-level attributes.

A second cluster integrates material inventories with LCA and logistics optimization to evaluate environmental and operational performance at the facility or system scale (Paz et al., 2023). In these studies, inventories are used to quantify CDW inputs, water consumption, and CO_2 emissions at recycling plants, as well as to optimize transport distances by matching waste sources with nearby recycling facilities (Paz et al., 2023).

Despite these efforts, the literature consistently identifies CDW supply variability as a major constraint. Unlike deconstruction planning strategies that operate at the project level, recycling depends on continuous waste inflows, making it highly sensitive to demolition activity cycles. This introduces uncertainty in RA production capacity and limits scalability. While inventory-based simulation approaches have been proposed to address this challenge (Prakash et al., 2021), their application remains limited, highlighting a gap between static inventory use and dynamic, forward-looking recycling systems. As reuse, deconstruction, and recycling focus primarily on EoL interventions, the discussion next shifts to circularity in design, which emphasizes earlier lifecycle decisions.

Circularity in Design

Although fewer in number, several studies highlighted the critical contribution of material inventories to achieving design for circularity. In these studies, inventories acted as a bridge between reclaimed materials and new design processes, enabling designers to integrate salvaged components effectively into building projects. Three central goals were emphasized across the literature: enhancing the use of reclaimed materials, verifying their structural performance, and adapting design methods to accommodate the irregular characteristics of non-standard components (Gordon & De Wolf, 2024; Nemeth et al., 2022).

Rather than treating reclaimed materials as design constraints, researchers explored how optimization-based approaches can turn inventory data into design opportunities. Gordon and De Wolf (2024) demonstrated that metaheuristic techniques such as genetic algorithms and particle swarm optimization can efficiently match available components from inventories with specific project needs. These optimization methods addressed the challenge of evaluating numerous possible combinations of salvaged elements, where variations in size, quality, and condition influence their suitability. In this way, material inventories provided the data foundation necessary to make the reuse of irregular or previously used components both practical and structurally sound.

Beyond material matching, inventories also informed early design decision-making by incorporating information about materials' EoL scenarios. Nemeth et al. (2022) showed that a component's future recoverability depends not only on its material type but also on its method of assembly whether through adhesives, layers, or mechanical fixings which affects disassembly potential and recyclability. Inventories that capture such assembly-level details allow designers to assess circularity during the design stage, ensuring that reused or reclaimed materials preserve their potential for future recovery and reuse.

The findings underscore the pivotal role of the design stage in advancing circularity within the construction sector. Effective circular design depends on comprehensive and accurate material inventories that document critical attributes such as type, condition, and structural integrity, without which the integration of salvaged components into new designs becomes impractical. This dependency is reinforced by the requirements of design-support and optimization tools, which rely on high-quality inventory data to adapt designs to available reclaimed materials. Applications such as genetic algorithms and particle swarm optimization illustrate how well-structured inventories enable informed material selection and support reuse-oriented design decisions that reduce environmental impacts (Gordon & De Wolf, 2024).

Data Types and Sources in Material Inventories

To support the integration of material inventories and CE strategies in advancing circularity in construction, it is crucial to acquire comprehensive material data from diverse sources such as written records, municipal archives, and federal building databases. The following discussion explores key data sources and collection methods.

Textual Data

Data such as building typology, the type and condition of heating systems, changes in building use, historical renovations, and incidents like fires can be gathered from written records, municipal archives, contractor reports, interviews with past or current occupants, and federal building databases (Pešta et al., 2024; Xiong et al., 2024; Bennet et al. 2023; Wu et al., 2021). These diverse sources support the development of predictive models to estimate missing buildings material information (Pešta et al., 2024; Xiong et al., 2024; Bennet et al., 2023), thereby contributing to the creation of a robust and comprehensive dataset. This enriched dataset can be integrated into parametric modeling frameworks to accurately estimate material quantities for buildings (Xiong et al., 2024). This approach is particularly valuable when dealing with limited data, which is often the case when generating material inventories for older buildings with scarce documentation because it allows for the reconstruction of material information without relying on full-scale on-site inspection (Xiong et al., 2024; Wu et al., 2021). Additional forms of textual data, such as records of hazardous material use like asbestos-containing materials or lead-based components, can be sourced from maintenance logs, health and safety reports, and renovation documentation (Wu et al., 2021). These results highlight that textual data such as maintenance logs, renovation histories, and safety reports appear frequently as a key input for material inventory modeling. This recurring pattern highlights its significance and suggests that Natural Language Processing (NLP) could play an important role in extracting structured information from these unstructured records. By leveraging NLP, stakeholders could transform archival data into usable inputs for predictive models, LCA tools, or BIM-based deconstruction planning, thereby expanding the scope and reliability of circular economy strategies.

Visual Data

Visual data were also widely reported as critical input for generating material inventories. Drone imagery and high-resolution photographs were frequently used to capture information on the location of construction and CDW sites, and the types of materials exist, supporting the development of site-specific material inventories that document resources available for recovery at individual projects (Mager & Blass, 2022). Image-based analysis further enabled the detection of spatial patterns and the classification of components by attributes such as material type, age, or condition, thereby improving the detail and context of material inventories (Mahmudnejad et al., 2023). Another important source of visual data was the 3D point cloud, typically generated through laser scanning. Point clouds were applied to create accurate as-built digital models of existing structures and to estimate material quantities or manually identify building components type (Guerriero et al., 2024). This method was particularly valuable for older buildings lacking original drawings, as it provided a reliable way to reconstruct material information. When integrated into BIM environments, point clouds supported the production of precise digital as-builts that enhanced both the comprehensiveness and accuracy of material inventories. Based on the reviewed literature, manual image analysis is often labor-intensive and susceptible to human error, which can compromise data quality and consistency (Mahmudnejad et al., 2023). As a result, the integration of machine learning (ML) techniques has been increasingly proposed to enhance both the accuracy and scalability of visual data processing (Mager & Blass, 2022). ML models not only improve pattern recognition and material classification but also enable deeper insights, such as detecting damage levels, identifying connection types, predicting historical use intensity, and estimating lifespan or reuse potential. These capabilities contribute to richer, more reliable inventories that are essential for supporting data-driven circular economy strategies, particularly in urban contexts where material flow mapping and reuse planning are critical.

Literature Limitations and Future Research

Although recent studies have advanced understanding of material inventories in circular economy (CE) strategies, several gaps remain. The literature shows a strong focus on material reuse (n = 14, 50%), while recycling (n = 8, 28%), deconstruction planning (n = 4, 15%), and circularity in design (n = 2, 7%) receive far less attention, reflecting trends noted by Benachio et al. (2020). Most studies rely heavily on textual data, with limited integration of visual or experimental sources. Only eight publications used these data types, and just two Mahmudnejad et al. (2023) and Mager and Blass (2022) exclusively used visual data. This imbalance highlights the need to expand the use of multimodal data to improve the accuracy and richness of material information. Technological adoption is also uneven. Current research centers on BIM, machine learning, and LCA, while emerging tools such as IoT, blockchain, and large language models (LLMs) remain underexplored (Rodrigo et al., 2023). Integrating these technologies could strengthen data traceability, interoperability, and automation, enabling more reliable and up-to-date material inventories.
Future work should develop life-cycle-integrated frameworks that allow continuous updates from design through demolition, moving beyond one-time end-of-life assessments. Research should also capture stakeholder perspectives to assess the adoption of material passports (MPs) for managing building data. Finally, advancing data quality and standardization through IoT, blockchain, and AI integration can establish material inventories as key enablers of circularity and sustainable transformation in construction.

Conclusion

This study advances understanding of how material inventories enable CE strategies in the construction industry. Through a systematic review of 28 studies, it synthesizes how inventories support material reuse, recycling, deconstruction planning, and circular design. The findings demonstrate that material inventories function as critical data infrastructures linking physical building assets with digital environments such as BIM, LCA, predictive modeling, and optimization tools. By providing material-specific information on type, quantity, condition, and provenance, inventories enable more accurate recovery assessment, structured deconstruction planning, and improved integration of reclaimed components into new designs.
A key contribution of this review is the classification of data types underpinning material inventories. Textual data remain dominant but are often fragmented, while visual data sources such as point clouds and drone imagery offer greater accuracy but face scalability challenges. The synthesis indicates that progress in circular construction depends on integrating these data types and adopting technologies capable of automating, validating, and updating material information across the building lifecycle.
The review also reveals persistent gaps, including a strong research focus on reuse relative to recycling, deconstruction planning, and circular design, as well as uneven technological adoption. While BIM, machine learning, and LCA are well established, emerging tools such as IoT-enabled sensing, blockchain-based material passports, and AI-driven data extraction remain underdeveloped.
These findings offer value for both research and practice. Practitioners can use the synthesized evidence to incorporate material inventories into demolition planning, reuse-oriented decision-making, and sustainability compliance, while reducing reliance on manual data collection. For researchers, the identified gaps highlight opportunities to develop interoperable, lifecycle-integrated inventory systems and scalable multimodal data integration methods. While significant progress has been made, some limitations remain. The review was limited to English-language journal articles indexed in Scopus and Web of Science, which may have excluded relevant regional, practice-oriented,

or grey literature (e.g. agency reports, technical briefs, and industry guidance) not indexed within these databases. Future research could strengthen robustness through broader search strategies and databases.

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