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BIM-ENABLED CIRCULAR CONSTRUCTION AND MATERIAL LIFECYCLE MANAGEMENT: A CRITICAL REVIEW OF DIGITAL STRATEGIES FOR RESOURCE-EFFICIENT AND LOW-CARBON BUILDING DELIVERY

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ABSTRACT

The integration of Building Information Modelling (BIM) with circular construction presents an opportunity to improve material efficiency and support low-carbon building delivery across the building lifecycle. This review examines how BIM-enabled digital strategies are being applied to circular construction and material lifecycle management, the resource-efficiency and environmental outcomes associated with these applications, the barriers limiting their implementation, and the research gaps that remain. The findings indicate that BIM is increasingly being integrated with lifecycle assessment, material passports, circularity assessment tools, material databases, traceability systems, and design-for-deconstruction approaches. These applications support material quantification, environmental assessment, reuse planning, recovery, and more informed design decision-making, with the strongest evidence concentrated in the design and construction phases. However, the review identifies persistent limitations in maintaining reliable material information across the full building lifecycle. Fragmented and incomplete data, inconsistent standards, implementation costs, skills gaps, organisational resistance, and interoperability challenges continue to constrain wider adoption. The review further finds that BIM-enabled digital capability does not automatically translate into measurable environmental benefits; outcomes depend on information quality, system integration, and the extent to which digital information informs project decisions. A conceptual framework is proposed positioning BIM as a lifecycle-oriented decision-support environment that connects material information, circular strategies, and measurable resource and environmental outcomes. The review highlights the need for interoperable, dynamic, and empirically validated digital workflows to support the transition towards circular and low-carbon construction.

Keywords: Building Information Modelling (BIM), Circular Construction, Material Lifecycle Management, Resource Efficiency, Building Decarbonisation.

1 INTRODUCTION

The building and construction industry is central to global economic development but has remained a major driver of waste generation, resource consumption and greenhouse gas emissions (Hamilton et al., 2024). The latest Global Status

Report for Buildings and Construction estimates that the sector accounts for approximately 37% of global carbon dioxide emissions and nearly 50% of global material extraction (Oloukoi et al., 2026). These impacts are associated with the production, assembly, transportation, maintenance, replacement, and end-of-life management of construction materials. Improving the environmental performance of buildings therefore requires methods that address material and resource flows across the entire building lifecycle (Oloukoi et al., 2026). In the predominantly linear model of construction, raw materials are extracted, transformed into building products, installed, used, and ultimately discarded. Circular construction and economy principles provide an alternative to this model and seek to maintain the value and utility of buildings for as long as possible (Rashidian et al., 2025; Chen et al., 2022). Strategies such as design for adaptability and disassembly, material reuse and recycling, resource recovery, and extended building and component lifespans are adopted for this purpose. Existing research identifies circular construction as extending beyond conventional waste management to encompass interventions across design, manufacturing, construction, operation and maintenance, and end-of-life stages (Çimen, Ö., 2021).

Implementing circularity across these stages, however, depends substantially on the availability, quality, accessibility, and continuity of information about buildings and their constituent materials. In conventional construction documentation, information is often distributed across drawings, specifications, schedules, databases, and project records. This makes it difficult to maintain reliable information about material quantities, properties, locations, maintenance histories, end-of-life pathways and reuse potential. The information gap can limit the ability of project participants to make informed decisions about material recovery and reuse. Recent research on material circularity identifies comprehensive material data and lifecycle traceability as important prerequisites for effective circular decision-making (Ranasinghe et al., 2024). Building Information Modeling (BIM) offers a potential digital foundation for addressing these challenges (Pibal et al., 2025; Al-Qazzaz et al., 2025). BIM enables the structured creation, exchange, management, and updating of information associated with built assets. This lifecycle-oriented information environment creates opportunities to connect geometric building information with material quantities, specifications, and other maintenance information or attributes needed to support circular decision-making. The convergence of BIM and circular economy principles has consequently attracted growing research attention. Studies have examined the integration of BIM with Lifecycle Assessment (LCA), digital material information, digital twins, and other technologies to support resource efficiency and sustainable construction (Rashidian et al., 2025). For instance, research on BIM-integrated LCA has identified opportunities for combining digital building information with environmental assessment to support circular and sustainable design decisions (Al-Qazzaz et al., 2025; Pibal et al., 2025). More recent reviews have expanded the discussion to digital technologies such as material passports, blockchain, spatial data acquisition, and artificial intelligence, demonstrating the growing role of digitalisation in enabling circular construction practices (Qazi et al., 2026; El Ammari et al., 2026; Aklashie et al., 2026). Although the body of research is expanding, important gaps remain. The relationship between BIM-enabled capabilities and resource-efficient material management across the complete building lifecycle remains fragmented despite specific examinations of technological applications, individual lifecycle stages and particular circular strategies (Akbarieh et al., 2020, El Ammari et al., 2026).

Recent research has also identified limited application of digital technologies during existing-building and end-of-life stages (Byers et al., 2024). Challenges are associated with material data availability and insufficient integration between digital tools, as well as practical circular construction implementation (Thirumal et al., 2024). These gaps call for a critical synthesis that moves beyond identifying technologies to examine how BIM-enabled approaches support specific circular strategies and material lifecycle decisions. This review investigates the role of BIM in enabling circular construction and pays particular attention to digital strategies that support resource efficiency and low-carbon building delivery. The review synthesises existing evidence across the building lifecycle to identify the principal BIM-enabled applications, circular strategies they support, environmental and resource-efficiency outcomes, implementation barriers, and emerging research directions. By consolidating these findings, the study seeks to clarify how BIM can function not just as a design and documentation tool but as an information infrastructure for improving material decision-making and advancing circularity throughout the building lifecycle.

2 METHODOLOGY

This study adopts a critical literature review approach to identify, evaluate, and synthesise peer-reviewed research examining the intersection of Building Information Modeling, circular construction, and material lifecycle management. The

The review is guided by four research questions that collectively examine the current state and future development of BIM-enabled circular construction. It specifically investigates how BIM is being applied to enable circular construction and material lifecycle management across different stages of the building lifecycle, as well as the resource-efficiency and low-carbon outcomes associated with these applications.

It further examines the implementation barriers that limit the adoption of BIM-enabled circular construction. Finally, the review identifies existing research gaps and emerging opportunities for advancing BIM-enabled circular construction and material lifecycle management.

2.1 Search Strategy

A structured literature search was conducted using major academic databases, including ScienceDirect, ERIC and Google scholar, selected for their coverage of digital built-environment, architecture, construction management, engineering and sustainability research. The search combines keywords relating to BIM, circular economy, construction, digital technologies, and material lifecycle management.

3 RESULTS AND DISCUSSION

3.1 BIM Applications Across the Building Material Lifecycle

The reviewed literature indicates that Building Information Modelling (BIM) is being positioned as an information infrastructure for circular construction and not just a tool for three-dimensional design and documentation. BIM's relevance to circularity stems from its capacity to associate building components with structured information that can be created, exchanged, updated, and reused throughout different stages of a building's lifecycle. Recent reviews identify BIM as the most prominent digital technology investigated in relation to circular construction, although its applications remain inconsistent across lifecycle stages (Thirumal et al., 2024).

3.1.1 BIM for Circular Design and Material Decision-Making

At the design stage, BIM is primarily used to embed material and component information into the digital building model, enabling designers to evaluate material quantities, characteristics, environmental impacts, and alternative design configurations before construction. This creates opportunities to include circular considerations earlier in the design process, where decisions concerning material selection can have long-term consequences for resource consumption and recovery (Pibal et al., 2025; de Lima et al., 2023). BIM-based lifecycle assessment frameworks, for example, have been developed to connect building models with environmental assessment and optimise material selection according to environmental performance. An important application is Design for Disassembly (DfD). This application does not treat demolition as the inevitable endpoint of a building but seeks to enable components to be separated and recovered for reuse or recycling (Heisel et al., 2025). BIM can support this approach by representing individual building elements and incorporating information required for their future identification, separation, and recovery (de Lima et al., 2023). Research has shown BIM-based disassembly models in which parameters associated with building components are extracted and used to support selective disassembly planning and component reuse (Sanchez et al., 2019; Sanchez et al., 2023). More recent work has further demonstrated the integration of BIM with DfD principles through digital modelling environments. de Lima et al. (2023), for example, developed a BIM-based approach using Revit and Dynamo to incorporate deconstruction information into building elements, provide designers with feedback on deconstruction parameters, and support the identification of potential destinations for recovered components. The study demonstrates that BIM can move DfD from a conceptual design principle towards a more operational digital workflow. DfD is significant because circularity is heavily influenced by decisions made before materials enter the construction site (Pierzchlewicz et al., 2025). If information about component identity, material composition, and recovery potential is added to the digital model at the design stage, that information can potentially remain available for later refurbishment, adaptation, disassembly, and recovery (de Lima et al., 2023; Pierzchlewicz et al., 2025). The literature therefore positions BIM as a mechanism for transferring circularity considerations from end-of-life management into upstream design decision-making.

3.1.2 BIM for Material Qualification, Lifecycle Assessment and Carbon Evaluation

Another major application concerns the measurement and evaluation of material and environmental performance. BIM models contain geometric and semantic information that can be used to derive material quantities and connect building elements with environmental datasets (Pibal et al., 2025). This creates a basis for integrating BIM with Life Cycle Assessment (LCA), enabling environmental impacts associated with alternative materials or design configurations to be evaluated during the design process (Pibal et al., 2025). BIM-based LCA research has consequently explored automated or semi-automated approaches for assessing material efficiency, embodied impacts, and alternative design solutions. This capability is highly relevant in low-carbon construction because material choices affect environmental impacts beyond the operational phase of a building. BIM-LCA integration can support earlier comparison of alternatives by linking quantities derived from the model to environmental impact information (McCord et al., 2024; Adesope et al., 2026). Mowafy et al. (2023) developed a parametric BIM-based LCA framework in which embodied environmental impacts (including emissions) were evaluated through computational design and optimisation procedures. The literature therefore suggests that BIM's contribution to circular construction supports decisions about which materials should be specified in the first place, how much material is required, and how alternative design configurations affect

lifecycle environmental performance. This positions BIM as a decision-support mechanism connecting design choices with resource efficiency and embodied environmental impacts.

3.1.3 BIM for Material Passports and Traceability

The development of material passports, which provide structured information about the materials and components incorporated into a building and can support their future reuse, is another notable application (Honic et al., 2021; Tabrizi et al., 2025). Recent research has identified BIM as the dominant digital technology used in material-passport development, reflecting its capacity to connect material information with specific building elements and locations (KC et al., 2024). The practical value of this approach is evident at the operation and end-of-life stages, when information about existing materials may be difficult to obtain. Honic et al. (2021) demonstrated a BIM-based material-passport approach for an existing building in which information obtained through laser scanning and other acquisition methods was incorporated into a BIM model. The final model was used to generate information on material quantities, recycling potential and environmental impacts. BIM can therefore transform existing building information into a resource for end-of-life decision-making (Honic et al., 2021; Honic et al., 2020). The literature also indicates, however, that material-passport applications remain relatively immature (Qazi et al., 2026; Mankata et al., 2025). A 2026 state-of-the-art review of 64 peer-reviewed studies found that BIM was the dominant technology used for material passports, but only 17% of the reviewed studies involved actual material passports developed for real-world projects (Qazi et al., 2026). The majority relied on conceptual frameworks or simulations. The same review identified disjointed lifecycle coverage, static BIM implementations, and inconsistent measurement protocols and definitions for circularity characteristics as persistent challenges (KC et al., 2024; Nadais et al., 2026). This finding is important for interpreting BIM's role in circular construction. The existence of material information within a BIM model will not automatically create a circular material-management system (Askar et al., 2024; Qazi et al., 2026). For BIM to support long-term material traceability, the information must remain accurate, accessible, interoperable, and updateable as buildings move from design and construction into operation, refurbishment, and eventual deconstruction (Bertin et al., 2020).

3.1.4 BIM for Deconstruction, Recovery and Reuse

BIM is progressively being investigated as a means of supporting a shift from conventional demolition towards selective deconstruction and material recovery (Mohammed et al., 2024). BIM-based disassembly models can provide information about component locations, characteristics, connections, and disassembly requirements, allowing recovery opportunities to be considered before physical intervention begins (Mohammed et al., 2024). This represents an important distinction between conventional construction information management and circular material management. Traditional project information is generally organised around building delivery and operation, whereas circular methods require information that remains useful when the building is altered or dismantled (Charef et al., 2019; Nikmehr et al., 2021). As a result, research on BIM and design for deconstruction has explored additional information requirements to identify and track components and determine their potential destinations for reuse or recycling (McNeil-Ayuk et al., 2024). The development of dedicated BIM-based deconstruction models further illustrates this shift. Researchers have proposed additional BIM dimensions and information structures specifically for end-of-life activities, including project, asset, and deconstruction information models that retain relevant information across successive lifecycle stages (Charef et al., 2019). Overall, the literature suggests that BIM applications for circular construction can be understood as forming a lifecycle information chain.

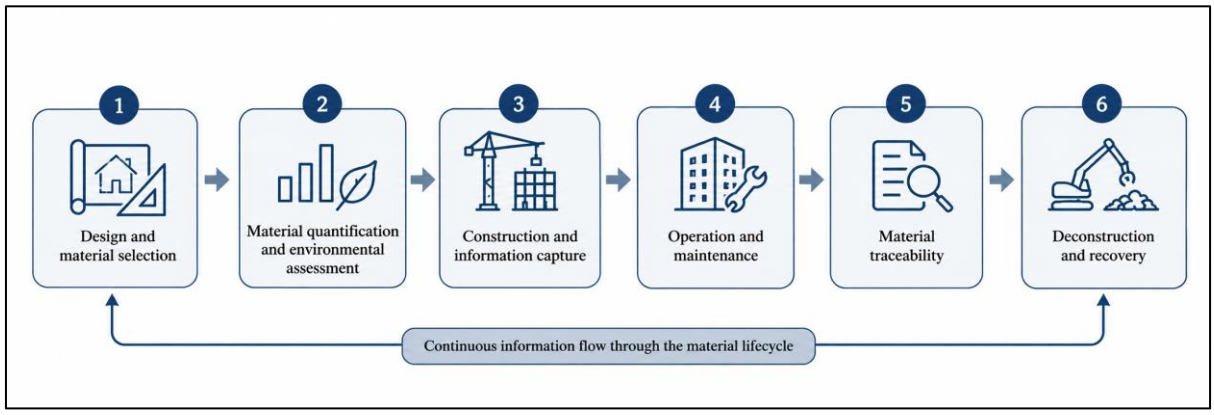


Figure 1: Lifecycle Information Chain

Source: Author's Construct (2026)

This lifecycle perspective is crucial because circular construction depends on maintaining information about materials beyond the point at which they are initially specified or installed. More recent reviews identify BIM as a major digital

enabler of circularity while highlighting that applications remain more developed in the design and construction phase than in later lifecycle stages (Nikmehr et al., 2021; Rebekka, 2023). The evidence therefore suggests that BIM is being applied across multiple lifecycle stages, but its role is evolving from project-delivery and design documentation towards a broader material-information infrastructure. At the same time, the literature indicates that achieving genuine lifecycle continuity remains constrained by fragmented information, interoperability limitations, and relatively limited real-world implementation of dynamic material information systems.

3.2 Resource Efficiency and Low Carbon Outcomes of BIM-Enabled Circular Construction

The environmental value of BIM-enabled circular construction is mostly expressed through better material utilisation, reduced waste, and earlier identification of carbon-intensive design decisions (Munonye et al., 2025). These benefits do not come from BIM independently; they emerge when building information is connected to quantity take-offs, environmental assessment, circularity metrics, or material-management processes.

3.2.1 Material Efficiency and Waste Reduction

A recurring outcome is improved control over material quantities and resource use. BIM provides a structured basis for extracting quantities from the building model, allowing material requirements to be assessed alongside design alternatives (Feng et al., 2022; Ekin et al., 2025). This creates opportunities to identify unnecessary material use and reduce losses associated with inaccurate estimation or design changes. Empirical work examining BIM implementation identifies design optimisation, material quantification and tracking as important dimensions through which BIM can influence resource efficiency (Jalaei et al., 2021). Lifecycle assessment, energy analysis, and prefabrication are also noteworthy strategies for waste management. BIM-supported coordination can also help identify design conflicts before construction, to reduce rework and the associated consumption of additional materials (Jalaei et al., 2021; Munonye et al., 2025). In this respect, the resource-efficiency benefit extends beyond the quantity of materials specified to preventing avoidable rework, thereby reducing material waste generated during project delivery. Moreover, material efficiency can move from being a qualitative aspiration to something that can be evaluated during design. Jiang et al. (2022) developed a BIM-based circularity assessment tool specifically to provide project stakeholders with material-efficiency insights, including the quantity and distribution of new and reused materials across building elements, showing how BIM information can be used to assess circularity at project level instead of simply documenting the finished design. The researchers subsequently extended this approach to accommodate different Levels of Development (LOD), allowing circularity to be assessed during the initial, design, and construction phases and not just after detailed information had been developed (Jiang et al., 2023). In the 2025 implementation, the tool incorporated three calculation models corresponding to different project phases and was evaluated through 12 user sessions and a renovation case project. This application is a practical demonstration of the value of BIM-based assessment as a decision-support mechanism. Stakeholders can receive information while design and construction decisions are still being made, enabling material choices and project strategies to be considered against circularity objectives rather than assessed retrospectively.

3.2.2 Embodied Carbon and Environmental Performance

A second outcome is embodied carbon, particularly through the integration of BIM with Life Cycle Assessment (BIM-LCA). BIM supplies detailed information about building components and quantities, while LCA provides the environmental assessment framework (Feng et al., 2022; Dsilva et al., 2023; Munonye et al., 2025). Xue et al. (2021) identify BIM-LCA integration as an important pathway for connecting material quantification with environmental evaluation and circular economy objectives. Their review highlights the potential for BIM and LCA to support material selection, quantify environmental impacts, and improve sustainability-oriented decision-making during building design. Other research demonstrates this principle through comparative and scenario-based assessment. BIM-LCA frameworks have been used to compare alternative structural systems and material configurations, enabling differences in embodied carbon to be identified within otherwise comparable building designs (Ma et al., 2025). Similarly, BIM-based assessment frameworks have incorporated circularity and lifecycle information to evaluate embodied carbon alongside dismantling, replacement, and residual-value considerations (Younes et al., 2025). This is significant because material efficiency and carbon reduction are closely connected but not interchangeable objectives (Dunant et al., 2025; Pauliuk et al., 2024). Reducing the quantity of material may lower environmental impacts, but substituting one material for another can produce different carbon outcomes depending on manufacturing processes, recycled content, durability, and end-of-life pathways (Younes et al., 2025; Xing et al., 2022). BIM-LCA therefore offers a means of evaluating these trade-offs rather than assuming that every circular intervention automatically produces a lower-carbon outcome (Tran et al., 2026; Ma et al., 2025). A 2026 BIM-LCA study of recycled aggregate concrete illustrates this point. Different recycled content scenarios produced differing environmental consequences, demonstrating that circular material choices require environmental assessment rather than being treated as inherently beneficial (Tran et al., 2026; Younes et al., 2025).

3.2.3 From Quantification to Design Decision Support

The evidence suggests that the most important contribution of BIM to resource efficiency and decarbonisation is its ability to bring quantitative environmental information into design decisions. The progression therefore looks like:

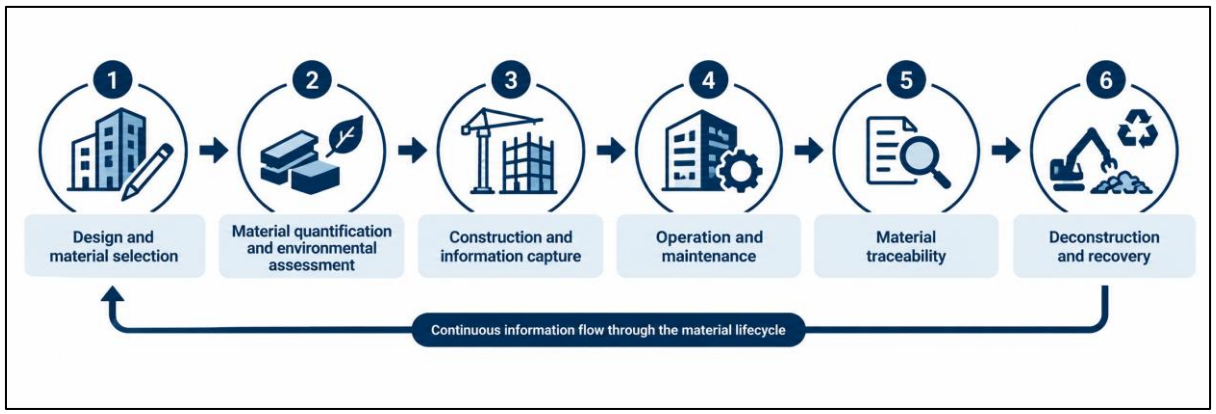


Figure 2: Information flow through material lifecycle

Source: Author's Construct, 2026

This presents a more consequential use of BIM than simple documentation. BIM-based assessment can allow designers to examine embodied carbon and circularity characteristics while design changes are still possible. The literature, however, does not support the conclusion that BIM automatically produces resource savings or carbon reductions (Burgess et al., 2025). Outcomes depend on the quality of model information, availability of environmental data, interoperability between BIM and assessment tools, and whether the resulting information informs project decisions.

3.3 Barriers to the Adoption of BIM-Enabled Circular Construction

3.3.1 Technological Barriers: System Integration and Interoperability

Interoperability is one of the most persistent technical constraints to the adoption of BIM-enabled circular construction (Kaewunruen et al., 2026; Shirowzhan et al., 2020). A practical workflow may require a BIM model to exchange information with environmental databases, material passports, RFID systems, digital twins, or other information platforms. Differences in data structures, proprietary formats, and software capabilities can prevent these systems from communicating reliably (Jia et al., 2026; Pibal et al., 2025). Akindele (2026) corroborates this challenge and identifies interoperability between digital systems and the absence of standardised data formats as persisting barriers to BIM-enabled circular workflows. The problem becomes even more significant when information must move beyond the original BIM authoring environment (Jia et al., 2026). Studies on digital circularity identify proprietary software and data silos as obstacles to interoperability, with more recent work on BIM–RFID integration reporting fragmented data flows and limited interoperability between BIM platforms, tracking technologies, and external databases (Aklashie et al., 2026). This is not a mere software inconvenience. If a material's identification, certification, location, or recovery information cannot be transferred between systems, the digital record becomes less useful when that information is needed for reuse or recovery (Jia et al., 2026; Aklashie et al., 2026). This challenge is evident in material passport research, where BIM is a dominant technology, but implementations remain mostly static and fragmented across lifecycle stages. Qazi et al. (2026), for example, found that only 17% of the 64 reviewed material-passport studies involved actual real-world passports, while the remainder were primarily conceptual frameworks or simulations.

3.3.2 Informational Barriers: Data Quality and Standardisation

Where systems can technically communicate, the information itself may be insufficient for circular decision-making (Tomczak et al., 2024; Qazi et al., 2026). Circular construction requires more than geometric information but also relies on associated data on composition, quality, location, environmental characteristics, connections, disassembly requirements, and potential recovery routes (Tomczak et al., 2024; Qazi et al., 2026). Existing literature shows that these data requirements are not yet coherently standardised. Qazi et al. (2026) identify uneven lifecycle coverage, inconsistent definitions and measurement protocols for circularity characteristics, and static BIM-focused implementations as important gaps in material passport research. Furthermore, research examining BIM requirements for circularity has shown that information relating to material composition, environmental impact, and disassembly can be incorporated into BIM, but inconsistent terminology and difficulties in representing component connections and disassembly information remain problematic (Tomczak et al., 2024)). This limitation is acute for existing buildings. A new BIM model can be populated with material information during design, whereas older buildings may lack reliable

and accessible digital records (Zhang et al., 2024; Qazi et al., 2024). The digital transformation review notes that applying digital tools to existing structures is considerably less straightforward, including the difficulty of creating reliable digital representations where information about demolished or existing assets is incomplete (Zhang et al., 2024).

3.3.3 Organisational Barriers

The technical constraints are reinforced by the structure of the construction industry itself. Circular BIM workflows require information to be shared between designers, contractors, manufacturers, facility managers, clients and other actors who may have different responsibilities, incentives and information practices (Sun et al., 2025). Systematic evidence on BIM–RFID applications identify organisational resistance, low stakeholder awareness and fragmented information flows as recurring barriers (Aklashie et al., 2026; Shehu et al., 2025). The difficulty is not whether individual professionals possess BIM skills or not; organisations must also establish processes for creating and sharing useful information beyond the immediate requirements of a construction project (Sun et al., 2025; Charef et al., 2021). This is especially challenging for circular practices because their benefits may occur long after the original design and construction decisions (Charef et al., 2021). An architect, for instance, who records detailed disassembly information might not benefit directly when a building is dismantled decades later. Contractors and suppliers may also incur additional data-management responsibilities without an immediate commercial return (Shehu et al., 2025; Charef et al., 2021). The literature therefore treats digital circularity as an organisational and governance issue rather than a technology-adoption problem alone.

3.3.4 Implementation Capacity, Cost and Validation

The transition from a successful digital demonstration to repeatable industry implementation is another major challenge to the adoption of BIM-enabled circular construction (Abd El-Hameed et al., 2025). Additional software, hardware, data preparation, training, and system integration are costly. These costs can be difficult to justify where circular requirements are not embedded in procurement processes or where markets for recovered materials remain uncertain (Stapleton et al., 2026). The literature also reveals a substantial implementation gap. Qazi et al. (2026) found that only a minority of material passport studies had progressed to real-world projects, while Abd El-Hameed's systematic review identified limited lifecycle coverage and insufficient integration between digital technologies as continuing weaknesses (Qazi et al., 2026; Abd El-Hameed et al., 2025). The 2024 digital-transformation review similarly reports high costs associated with digitising existing buildings and observes that much of the literature emphasises environmental potential more readily than practical implementation (Abd El-Hameed et al., 2025; Zhang et al., 2024). Skills also matter here. Implementing a circular BIM workflow requires professionals who understand a wide range of concepts including BIM authoring, material data, lifecycle assessment, circularity requirements and information management (Aklashie et al., 2026; Monzeri et al., 2025). Consequently, adoption may be constrained even where the necessary technologies are commercially available.

3.4 Critical Research Gaps and Conceptual Framework

The review identifies substantial progress in the application of BIM to circular construction, but also identifies fragmented evidence across lifecycle stages, technologies, environmental outcomes, and implementation contexts. The literature demonstrates that BIM can support material quantification, circularity and lifecycle assessment, material passports, traceability, deconstruction, and reuse. However, these applications have not yet developed into a consistently validated, lifecycle-wide approach for managing building materials as resources. Four interconnected research gaps emerge from the review.

3.4.1 Lifecycle Continuity and Material Information

The first gap is the lack of continuous and reliable material information across the building lifecycle. Existing research is more developed around design and construction than operation, refurbishment, deconstruction, and recovery. Material passports and BIM-based databases provide promising approaches, but their implementation remains relatively immature. Data generated during design may not be sufficiently accessible, accurate, or detailed when materials are considered for maintenance or refurbishment decades later. Future research should therefore investigate dynamic lifecycle information systems that preserve material identity, environmental characteristics, maintenance history and recovery potential throughout successive lifecycle stages.

3.4.2 Interoperability

The second gap concerns the interoperability and standardisation of circularity information. BIM can structure building and material information, but circular construction requires data that extend beyond conventional geometry and specifications. Information concerning material composition, environmental impacts, disassembly requirements, and recovery potential must also be exchanged between BIM platforms, LCA tools, product databases, and other digital systems. Tomczak et al. (2024) demonstrate the potential for representing circularity requirements within BIM, while

also identifying inconsistencies in terminology and difficulties in expressing disassembly information and component connections. Pibal et al. (2025) also highlight the need for additional data integration to connect BIM with lifecycle and circularity assessment. The research gap therefore extends beyond software compatibility to the absence of shared information structures and machine-readable requirements for circular construction. Future research should develop interoperable data architectures that allow circularity information to remain usable across software platforms, organisations and lifecycle stages.

3.4.3 From Digital Capability to Measurable Outcomes

The reviewed literature demonstrates that BIM can support material optimisation, waste reduction, environmental assessment and circular decision-making, but digital capability does not automatically produce resource or carbon savings. The pathway from a digital model to an environmental outcome depends on whether the information generated is accurate, available at the appropriate decision point, connected to relevant environmental data, and actually used to modify project decisions. Jiang et al. (2025) illustrate progress in this direction through a BIM-based circularity assessment tool that supports evaluation across different project phases and Levels of Development. Broader empirical evidence, however, remains limited.A related challenge is the consistency of the metrics through which these outcomes are evaluated. Akindele (2026) identifies the absence of common circularity performance indicators as an important research gap, noting variation in measures such as waste diversion, embodied-carbon savings, and circularity indices. Generating more empirical evidence should be accompanied by greater consistency in the indicators used to evaluate circular outcomes across projects.

The significance of validating digital or predicted performance against realised outcomes is also demonstrated in the wider sustainable-building literature. In a systematic review of 22 U.S. studies, Akindele (2026a) found considerable variability between predicted and actual building energy performance, with modelling errors associated with occupancy assumptions producing over-predictions of up to 25% in one reviewed case.

The review emphasises metered or validated performance, commissioning and continuous assessment rather than reliance on design-stage predictions alone. Though these findings concern operational energy rather than circular material flows, they reinforce the need for BIM-enabled circular strategies to progress from demonstrating digital capability towards verifying measurable environmental outcomes.

Future studies should therefore measure the actual effects of BIM-enabled circular decisions using indicators such as material waste avoided, quantities reused or recovered, embodied carbon changes, resource consumption, and component recovery rates. This would demonstrate what digital systems can achieve in practice and not just what they represent.

3.4.4 Real-World Implementation and Scalability

The fourth gap concerns the transition from individual digital demonstrations to repeatable industry-wide implementation. Thirumal et al. (2024) show that digital adoption for circular construction is influenced by technological, organisational, investment, and data-related factors. Thus, the scalability of BIM-enabled circular construction cannot be addressed through technology alone. Substantive research is needed on how circular information requirements can be embedded into processes such as procurement, project information requirements, construction documentation, asset management and deconstruction planning.

Evidence from the broader green-building sector illustrates how procurement and policy mechanisms can help translate sustainability objectives into formal project requirements. Akindele (2026b) shows that U.S. green-building certification operates within an interconnected system of federal, state and local policies, with mechanisms such as public procurement, building codes and incentives contributing to the institutionalisation of sustainability requirements.

For BIM-enabled circular construction, a comparable transition could embed requirements for material information, lifecycle assessment, reuse potential and end-of-life planning within formal procurement and project information requirements instead of leaving them as predominantly voluntary digital practices.

Greater attention is also needed to the existing building stock, where incomplete records make the creation of reliable digital material inventories substantially more difficult. Longitudinal studies and multi-project case studies would be valuable for determining whether BIM-enabled circular workflows remain effective beyond controlled research demonstrations.

3.4.5 Conceptual Framework

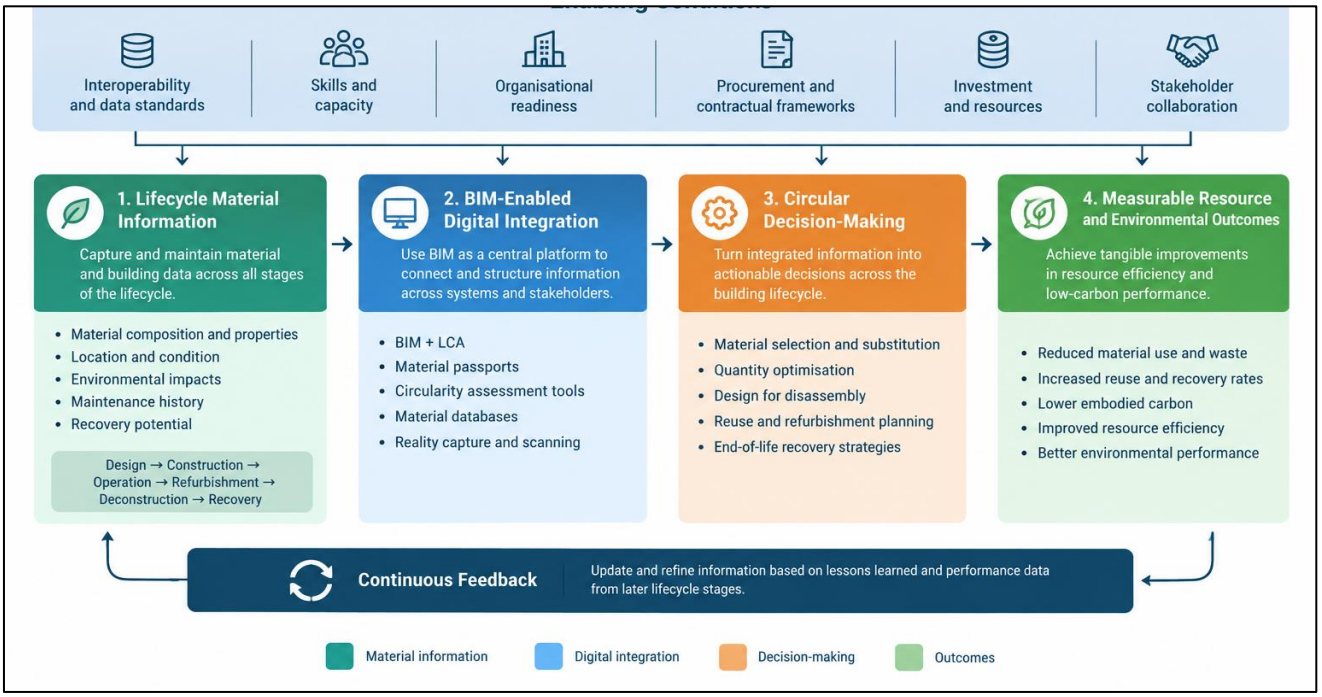


Figure 3: Conceptual framework for BIM-enabled circular construction

Source: Author's Construct, 2026

The identified gaps support a conceptual framework in which BIM functions as an information and decision-support layer rather than as an environmental outcome in itself. The proposed framework consists of four principal stages: Lifecycle material information, BIM-enabled digital integration, circular decision-making, measurable resource and environmental outcomes.

The first stage captures material and building information generated across design, construction, operation, refurbishment and end-of-life. BIM then provides the central digital environment for connecting and structuring this information with complementary systems such as LCA databases, material passports and reality-capture technologies. The resulting information supports decisions concerning material selection, quantity optimisation, design for disassembly, reuse, refurbishment and recovery. These decisions ultimately influence measurable outcomes including waste reduction, material recovery and embodied environmental performance. Data standards, skills, governance, procurement, investment and stakeholder collaboration are the enabling conditions across the entire framework. Feedback from later lifecycle stages should also update the digital information environment, creating a continuous information cycle.

4 CONCLUSION

This review examined the role of BIM-enabled digital strategies in supporting circular construction and material lifecycle management, with emphasis on resource efficiency, low-carbon building delivery, and the barriers to implementation. The findings demonstrate that BIM has evolved beyond its conventional role in geometric modelling and project coordination. When integrated with Lifecycle assessment, material passports, circularity assessment tools, digital material databases, and design-for-deconstruction approaches, BIM can provide valuable information for material selection, quantification, environmental assessment, traceability, and recovery. However, the evidence also indicates that research is concentrated around design and construction, while the management of material information throughout operation, refurbishment, deconstruction, and recovery remains underdeveloped. This limits the ability of BIM to function as a truly lifecycle-oriented information environment. The review further shows that BIM-enabled methods can support resource efficiency and carbon-conscious decision-making, but digital capability does not automatically produce environmental benefits. Outcomes depend on the quality, completeness, interoperability, and timely use of information in project decisions. Several interconnected barriers continue to limit wider implementation. These include interoperability limitations, inconsistent data standards, incomplete material information, high implementation costs, skills gaps, organisational resistance, fragmented stakeholder responsibilities, and limited real-world validation. Addressing these challenges requires coordinated interventions rather than isolated digital solutions.

The principal research gap is therefore not a lack of digital technologies, but the absence of sufficiently integrated, dynamic, and empirically validated workflows that maintain actionable material information throughout the building lifecycle. Future research should prioritise interoperable BIM-enabled frameworks that connect material data with circularity assessment, environmental evaluation, reuse, and recovery processes while demonstrating measurable outcomes across real projects. The transition towards circular and low-carbon construction will depend on moving BIM from a project-centred modelling tool towards a lifecycle decision-support environment in which material information remains connected, traceable, and actionable from design through end-of-life.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

Disclosure of conflict of interest

The authors declare no conflicts of interest regarding this manuscript.

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