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**Review paper**

# Assessment methods as strategic tools to advance circular economy in the construction sector

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**ABSTRACT**

The construction sector faces pressing environmental challenges driven by high resource consumption, elevated waste generation, and significant greenhouse gas emissions. The circular economy (CE) has emerged as a restorative and regenerative alternative to traditional linear models, promoting resource efficiency, material recirculation, and long-term sustainability. Effective integration of CE principles into the built environment, however, depends on the availability of assessment methods capable of measuring circularity, evaluating material flows, and identifying regeneration opportunities. This paper presents a theoretical analysis of existing sustainability assessment methods, including BREEAM, LEED, and DGNB, and evaluates their capacity to operationalise circularity in the construction sector. Results show that while current tools incorporate aspects of sustainability, they lack specific metrics to measure circularity indicators, such as material loops, design for disassembly, resource recovery potential, and system regeneration. A conceptual framework and an expanded set of indicators are proposed to enhance the assessment of circularity and support transitions toward circular construction practices. The paper contributes to the theoretical foundations needed to guide policy development, industry adoption, and collaborative strategies in circular built-environment systems.



## 1 Introduction

The construction sector remains one of the most resource-intensive industries worldwide, responsible for substantial raw material extraction, high energy consumption, and a significant share of global waste generation. This long-standing dependence on linear resource flows, characterized by extraction, production, use, and disposal, has amplified environmental pressures and exposed the structural inefficiencies of a throughput-oriented development model [1]. As urbanisation accelerates and the global building stock continues to expand, the sector faces increasing challenges related to resource scarcity, embodied carbon, waste management, and long-term environmental degradation [2].

In this context, the Circular Economy (CE) has emerged as a transformative paradigm that can decouple economic growth from resource depletion. Applied to the built environment, CE promotes strategies such as high-value reuse of construction and demolition waste (CDW), design for adaptability and disassembly, modular construction, material recirculation through industrial symbiosis, and the integration of digital product information via Material Passports (MPs), Digital Product Passports (DPPs), and Building Logbooks [3], [4]. These strategies aim to extend the life cycles of materials, conserve value, and minimise environmental impacts across all project phases [5].

Despite the growing interest in CE, its operationalisation within the construction sector remains limited and inconsistent. A central challenge lies in the absence of harmonised, robust, and quantifiable assessment methods capable of evaluating circularity at the material, component, and building scales [6]. Existing sustainability frameworks, such as LEED, BREEAM, DGNB, HQE, and Level(s), provide essential metrics for environmental performance but were not originally designed to assess circularity [7]. As a result, many circularity-related aspects, including material flow tracking, component recoverability, regeneration potential, and value-retention efficiency, remain only partially captured or entirely unaddressed.

Assessment tools exhibit several methodological and practical shortcomings:

- **Insufficient material flow transparency** limits the ability to evaluate circular strategies throughout the life cycle;

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- **Lack of consistent indicators for reuse, disassembly, and repairability**, which are essential in CE-aligned design processes;
- **Oversimplified end-of-life (EoL) modelling**, often based on generic recycling rates rather than project-specific recovery pathways;
- **Fragmented data structures and limited interoperability** between sustainability tools, Building Information Modelling (BIM), and LCA/LCC databases;
- **Weak integration with emerging digital infrastructures**, such as Digital Product Passports and building-level materials databases required under new European regulatory frameworks.

These gaps highlight the need for a new generation of assessment methods that are positioned not only as evaluative instruments but also as strategic tools to steer design, procurement, construction, and maintenance toward circular and regenerative outcomes [8].

This paper critically examines the current state of assessment methods in the construction sector and evaluates their capacity to support the implementation of CE. It identifies structural limitations, conceptual inconsistencies, and digitalisation bottlenecks that hinder circularity measurement and decision-making [2]. Building on this analysis, the paper proposes a set of enhanced CE-aligned indicators and methodological considerations to strengthen assessment frameworks and position them as strategic enablers of circularity. By advancing more consistent, transparent, and interoperable assessment practices, the study aims to contribute to the ongoing transition toward a more resource-efficient and circular construction sector [2].

This study advances the current body of knowledge by moving beyond descriptive comparisons of sustainability assessment tools and providing a structured analysis of their limitations in operationalising circularity. Unlike previous reviews, which primarily assess environmental performance, this work conceptualises assessment methods as strategic instruments for enabling circular transitions. Furthermore, it proposes a preliminary set of circularity-oriented indicators and identifies key requirements for integrating digital traceability, life cycle thinking, and value-retention mechanisms into future assessment frameworks.

## 2 Theoretical background: circular economy in construction

### 2.1 From linear to circular systems

The construction sector has historically operated under a linear resource model, characterised by intensive raw material extraction, energy-intensive manufacturing processes, short utilisation periods for many building components, and large volumes of construction and demolition waste (CDW) disposed of at the end of the life of buildings [2]. This extract–produce–consume–dispose pathway results in significant material losses and exerts increasing pressure on natural ecosystems, especially as global demand for buildings and infrastructure continues to rise. Urbanisation trends, the expansion of building stock, and the need for continuous upgrades of aging infrastructure amplify the limitations of this model, making its long-term viability increasingly untenable [9].

In contrast, CE principles seek to redefine material and resource flows by maintaining value within the system for as long as possible. CE models emphasise strategies such as reuse, refurbishment, remanufacturing, design for disassembly, high-quality recycling, and regenerative material cycles [9]. These approaches aim to extend service life, reduce dependency on primary resource extraction, and minimise environmental impacts associated with material production and disposal. Transitioning to CE therefore challenges the construction industry to replace traditional demolition practices with selective deconstruction, prioritise long-life components, and enable future adaptability, reversibility, and transformation of building systems [9].

To conceptualise these transitions, CE frameworks, including the widely referenced Ellen MacArthur Foundation's butterfly diagram, provide a structured representation of how materials circulate through biological and technical cycles [2]. Biological cycles refer to renewable, biodegradable materials that can safely return to natural systems, supporting regenerative processes such as composting, nutrient cycling, and the renewal of bio-based materials [10]. Technical cycles, by contrast, involve industrial materials such as metals, polymers, ceramics, and concrete, which must circulate through processes that retain or restore value: maintenance, repair, reuse, refurbishment, remanufacturing, and recycling. CE models emphasise value retention hierarchies, favouring high-value strategies (reuse, remanufacturing) over lower-value ones (downcycling), thereby aiming to maximise material utility across multiple life cycles.

Within the construction sector, strengthening technical cycles is particularly critical due to the long lifespan of built assets, the capital-intensive nature of building components, and the substantial embodied carbon and environmental impacts associated with the use of mineral and industrial materials [9]. Long service life, however, does not inherently ensure circularity. Without material traceability, disassembly-oriented design, and efficient recovery infrastructure, many materials ultimately follow a linear degradation pathway, ending up in landfills or low-value recycling streams.

Transitioning from linear to circular systems, therefore, requires integrating CE principles across all stages of the building lifecycle, from concept design and procurement to construction, operation, maintenance, renovation, and end-of-life planning [9]. Achieving this transition depends on enabling conditions, such as robust, harmonised data structures, digital workflows that embed circularity considerations (e.g., BIM-based material tracking), and assessment tools capable of consistently and at scale quantifying circularity performance. Without reliable data and metrics, circularity remains aspirational rather than operational, reinforcing the need for new methodologies that align design, material selection, and lifecycle management with CE objectives.

### 2.2 Barriers to circularity in construction

Despite growing interest in CE principles and a steady increase in pilot initiatives worldwide, the transition toward circular construction remains hindered by a series of persistent structural, regulatory, technical, cultural, financial, and organisational barriers [10]. These obstacles affect all stages of the value chain, from material sourcing and manufacturing to design, procurement, construction, operation, renovation, and end-of-life processes, limiting the scalability and mainstream adoption of CE practices. The complexity of these barriers reflects the deeply embedded linear logic that has shaped construction industry practices for decades.

A central constraint lies in the limited availability, quality inconsistency, and market immaturity of secondary materials. Although CDW is one of the most significant waste streams globally, only a small fraction is recovered at a quality suitable for high-value reuse or remanufacturing. Contamination, inefficient sorting technologies, and the prevalence of composite materials complicate recovery processes [9]. Additionally, the absence of controlled and selective deconstruction practices, often replaced by rapid demolition, results in a loss of material integrity, limiting opportunities for component reuse. These challenges hinder the development of robust secondary material markets and prevent circular practices from becoming economically viable [10].

Regulatory and institutional barriers further inhibit circularity. Building codes, safety standards, and liability rules often restrict the reuse of structural or non-structural components due to concerns about performance reliability, traceability, warranties, and compliance [9]. Many standards still privilege virgin materials, and national regulations frequently lack harmonisation, making it challenging to apply circular strategies consistently across regions. Public procurement systems, which influence a large share of construction demand, often prioritise cost minimisation or traditional compliance pathways over circular performance, reinforcing linear procurement habits.

Another critical barrier is the lack of material traceability across the building lifecycle. Most construction products currently enter the built environment without digital identities or persistent data records. As buildings typically last several decades, the loss of information regarding material composition, embodied impacts, hazardous substances, and potential reuse pathways renders high-value recovery nearly impossible [9]. Frequent changes in ownership, fragmented documentation practices, and insufficient integration of digital tools across the value chain intensify this issue.

Digitalisation gaps compound this challenge. Many organisations lack digital infrastructures and platforms capable of recording, updating, and transferring material history in interoperable formats. Integration with tools such as Building Information Modelling (BIM), life-cycle assessment (LCA) software, and emerging frameworks like Material Passports (MPs), Digital Product Passports (DPPs), and digital building logbooks remains limited [3]. Data interoperability, inconsistent ontologies, and proprietary file formats hinder the integration of circularity criteria into decision-making processes during design and procurement, thereby restricting the flow of adequate information.

Economic and market-related barriers also persist. Circularity often requires higher upfront costs, investments in new technologies, development of reverse logistics, and the establishment of refurbishment or remanufacturing facilities [10]. These costs, combined with the uncertainty of resale markets for reclaimed components and the inconsistent supply of secondary materials, create perceived financial risks that discourage stakeholders from engaging in circular practices. The absence of mature business models, such as product-as-a-service, leasing, or material take-back schemes, further limits adoption.

Cultural and behavioural barriers contribute to the slow pace of the transition. The construction industry remains highly conservative, risk-averse, and oriented toward conventional supply chains. Designers, contractors, and clients often lack awareness, expertise, or confidence in circular strategies [10]. Limited training, insufficient knowledge transfer, and traditional performance indicators (e.g., cost and delivery time) overshadow circularity considerations. These cultural norms perpetuate linear practices and hinder experimentation with innovative circular approaches.

Finally, one of the most fundamental limitations is the absence of transparent, harmonised, and widely accepted metrics for measuring circularity. Existing sustainability certification systems were developed under environmental paradigms and therefore lack dedicated definitions, indicators, and benchmarks for circularity [1]. This results in fragmented measurement approaches, superficial inclusion of circularity-related credits, and a general inability to quantify material recovery potential, design reversibility, value-retention capacity, or systemic regeneration. Without shared definitions and standardised metrics, circularity remains difficult to compare across projects, assess consistently, or incorporate into regulatory frameworks [11].

Within this context, assessment methods emerge as strategic tools. By establishing clear definitions, harmonised data requirements, measurable indicators, and traceable documentation structures, robust assessment methods can mitigate many of these barriers [10]. They can support informed decision-making, facilitate regulatory alignment, enhance digital interoperability, and guide the construction industry toward a systematic transition to linear-to-circular and regenerative practices.

## 3 Review of sustainability assessment methods

### 3.1 LEED

The Leadership in Energy and Environmental Design (LEED) system, developed by the U.S. Green Building Council (USGBC) [12], is the most internationally recognised and widely adopted sustainability certification framework [13]. LEED evaluates buildings through a credit-based structure that covers energy performance, indoor environmental quality, water efficiency, site sustainability, and materials and resources. Within this structure, the Materials and Resources category aims to improve environmental performance by encouraging responsible material sourcing, increasing the use of recycled content, promoting effective construction waste management, and enhancing transparency through Environmental Product Declarations (EPDs) and material ingredient reporting programs.

From a circularity perspective, LEED contributes indirectly by guiding project teams toward environmentally conscious decisions, such as reducing construction waste, favouring materials with lower embodied impacts, and encouraging the reuse of existing structures [14]. Requirements related to construction and demolition waste management, for instance, aim to divert waste from landfills [15]. At the same time, credits for reducing building life-cycle impacts incentivise adaptive reuse and renovation over new construction. Similarly, promoting EPDs increases the availability of life-cycle information on materials, potentially supporting informed decision-making in the early design stages.

Despite these positive contributions, LEED's alignment with CE principles remains limited. LEED was initially conceived to address environmental sustainability, and its material-related credits focus primarily on waste diversion rates, recycled-content proportions, and product transparency [15]. These indicators reduce environmental burdens but do not reflect deeper circularity objectives such as value retention, loop closure, multi-cycle material performance, or long-term adaptability [6]. For example, although LEED rewards the reuse of existing buildings, it does not explicitly incentivise design strategies that would ensure future recoverability of components, such as modular construction systems, reversible connections, or design for disassembly [15]. Consequently, the framework encourages the reuse of past building elements but does not prepare buildings for future reuse cycles.

Another critical limitation relates to end-of-life considerations. LEED evaluates waste management during construction but does not assess the recovery potential of materials during future renovation or demolition [12]. End-of-life scenarios are not explicitly modelled, nor does the system provide methods for estimating the long-term recirculation potential of materials. This short-term focus prevents LEED from capturing the temporal dimension of circularity, where materials and components are expected to circulate through multiple life cycles over several decades [15].

Material traceability is also insufficiently addressed. Although EPDs and material ingredient disclosures promote transparency, they do not offer persistent digital identities for materials or components. LEED does not incorporate digital systems such as Material Passports, Digital Product Passports, or building-level logbooks that record material attributes throughout the building's lifespan [12]. Without such tools, it becomes difficult to trace materials over time, undermining future opportunities for reuse, refurbishment, or high-value recycling.

Additionally, LEED's assessment approach is static. Certification occurs at a single point in time, typically upon project completion. Circularity, however, is dynamic by definition: materials age, degrade, are replaced, and may re-enter new cycles [12]. A one-time certification cannot capture these transformations, nor can it evaluate whether buildings remain adaptable or suitable for future disassembly. Therefore, LEED's structure is incompatible with the continuous monitoring required for operational circularity [6].

Finally, the LEED system's structural characteristics limit its potential to drive circular change. Its flexible points-based approach allows projects to obtain certification without prioritising material-related credits, thereby weakening the influence of circularity-enabling strategies [6]. Moreover, its criteria rely heavily on market availability of products with specific certifications, which vary widely by region, creating inconsistent opportunities for circular practices across project locations.

### 3.2 BREEAM

The Building Research Establishment Environmental Assessment Method (BREEAM) is one of the most established and influential sustainability certification frameworks, widely implemented across Europe and internationally [13]. Compared to other systems, BREEAM offers a broader and more detailed coverage of material-related criteria, integrating sustainability considerations across categories such as management, energy, water, materials, waste, health and wellbeing, and pollution. Within its materials domain, BREEAM places particular emphasis on LCA, responsible sourcing of construction products, material efficiency, construction site resource management, and the use of EPDs [16]. These elements collectively enable a more comprehensive evaluation of embodied impacts than other frameworks, particularly by encouraging reductions in resource consumption and promoting transparency in material supply chains.

The inclusion of LCA within BREEAM is particularly noteworthy, as it enables a systematic analysis of the environmental burdens associated with building components throughout their entire life cycle. This supports informed decision-making at early design stages and fosters the selection of materials with lower embodied impacts [17]. Additionally, BREEAM's focus on responsible sourcing and material efficiency reflects a broader effort to reduce primary resource extraction and minimise waste generation across project phases. In these respects, BREEAM provides a more robust assessment structure than LEED for examining material-related environmental performance.

However, when evaluated through the lens of CE, several limitations become apparent. Although BREEAM encourages resource-efficient design, it does not provide structured mechanisms to track dynamic material flows throughout a building's life cycle [6]. The system does not quantify reuse potential, assess the reversibility of building components, or map realistic end-of-life recovery routes [17]. This lack of material-flow modelling limits projects' ability to anticipate multiple life cycles for building components, a core principle of CE.

Moreover, BREEAM does not fully integrate circularity-specific design strategies. While certain credits indirectly support principles such as durability or adaptability, explicit recognition of design for disassembly, modular construction, remanufacturing potential, or long-term material value retention remains limited [16]. BREEAM's methodology continues to focus primarily on reducing environmental impacts, rather than enabling the regenerative, multi-cycle approaches central to CE implementation.

Material traceability within BREEAM is also fragmented. Although requirements for EPDs and responsible sourcing improve transparency, they do not provide the persistent and structured information needed to track materials throughout the building's lifespan [17]. The system does not incorporate digital tools such as Material Passports, Digital Product Passports, or building-level digital identities that would support long-term documentation of material attributes, facilitate selective deconstruction, or enable high-value reuse in future cycles [16]. Without such traceability mechanisms, circularity remains difficult to operationalise beyond the construction stage.

End-of-life considerations represent another critical gap. BREEAM addresses waste management during construction and operation; however, its treatment of the end-of-life stage is static and simplified [17]. The system does not evaluate realistic scenarios for component recovery, reuse in secondary markets, or integration into industrial symbiosis networks. This limitation restricts BREEAM's ability to support multi-cycle material strategies and fails to account for the logistical and economic complexities associated with future material recovery.

In summary, BREEAM provides a stronger foundation for evaluating embodied impacts and resource efficiency than LEED, particularly through its integration of LCA and responsible sourcing criteria [16]. Nevertheless, its methodological structure remains oriented toward environmental sustainability rather than circularity. The absence of dedicated indicators for material recirculation, long-term traceability, building adaptability, value-retention strategies, and lifecycle-integrated recovery pathways means that BREEAM falls short of enabling the systemic shift required for CE implementation [13]. While it helps reduce environmental impacts, it does not provide the tools needed to assess or accelerate the transition from linear to circular construction systems.

### 3.3 DGNB

The German Sustainable Building Council (DGNB) certification system is widely regarded as one of the most comprehensive and methodologically robust sustainability assessment frameworks currently in use. Its distinguishing feature lies in the balanced integration of environmental, economic, sociocultural, technical, and process-related performance criteria, reflecting a holistic understanding of building performance [18]. Unlike LEED or BREEAM, DGNB adopts an explicitly life-cycle–oriented perspective, incorporating both LCA and Life-Cycle Costing (LCC) as central components of its methodology [19]. This long-term approach enables a systemic evaluation of environmental burdens, operational and maintenance requirements, and economic implications throughout the building's lifespan, positioning DGNB as one of the most analytically rigorous certification systems available.

DGNB also incorporates optional criteria that are particularly relevant to CE principles, including adaptability, convertibility, and disassembly [19]. These criteria encourage design strategies that support flexible spatial configurations, facilitate future modifications, and enable the recovery of building components at the end of life. In doing so, DGNB acknowledges the importance of designing buildings as dynamic systems that can respond to evolving functional needs and material recovery pathways [6]. This makes DGNB the closest among existing sustainability certification systems to aligning with CE objectives.

Yet, despite these strengths, DGNB is not fully operationalised within a circularity framework. Several substantive gaps remain that limit its ability to support or measure long-term material recirculation. For instance, DGNB does not quantify the recirculation potential of materials or components beyond general assessments of recyclability [19]. The system lacks indicators that evaluate the feasibility of reintroducing materials into technical loops through reuse, refurbishment, or remanufacturing. Consequently, DGNB cannot assess whether materials retain functional value across multiple life cycles, an essential dimension of CE.

Similarly, although DGNB addresses adaptability and disassembly, it does not systematically evaluate whether recovered components can enter secondary markets or whether their properties, durability, and condition are suitable for high-value reuse [18]. The framework also lacks explicit metrics for value-retention strategies, including the durability of materials across multiple cycles, residual value forecasting, and quantification of the long-term economic benefits associated with material conservation [19]. These omissions limit DGNB's ability to assess whether buildings support regenerative material flows or merely reduce their environmental impacts.

Material traceability is another significant limitation. While DGNB encourages transparency through LCA and LCC, it does not integrate emerging digital tools, such as Material Passports, Digital Product Passports, or digital building logbooks, which record material attributes throughout the building's service life. Without such tools, the system cannot support long-term tracking of materials, documentation of component-level information, or data-sharing mechanisms essential for circularity. This lack of traceability undermines the ability to plan for future reuse, manage material stocks, or operationalise disassembly strategies.

Taken together, these limitations demonstrate that DGNB, although more advanced than LEED or BREEAM in addressing long-term design and material considerations, remains primarily a sustainability assessment framework. Its partial alignment with CE principles reflects an evolution toward circularity, but not a complete integration of circularity metrics into its core methodology [19]. The system advances several essential preconditions for circularity. Still, it does not yet provide a comprehensive evaluation of material recirculation, multi-cycle value retention, or the systemic transformation required for circular construction [18]. As such, DGNB remains a sustainability-oriented tool with circularity features, rather than a method for assessing circularity.

## 4 Comparative analysis of LEED, BREEAM, and DGNB

A comparative examination of LEED, BREEAM, and DGNB reveals fundamental differences in scope, methodological depth, and alignment with CE principles [19]. While all three systems aim to improve the environmental performance of buildings, their capacity to support circularity varies significantly due to the historical context in which they were developed, the ecological paradigms they prioritise, and the types of indicators they include.

LEED remains the most widely recognised framework globally, mainly due to its accessibility, market penetration, and emphasis on environmental transparency and resource efficiency. However, its material-related credits primarily focus on waste diversion, recycled content, and responsible procurement. These indicators encourage reductions in environmental impact but do not fully address the value-retention strategies, multi-cycle material flows, or design-for-disassembly principles required for circularity [18]. LEED evaluates materials primarily now of construction, with minimal attention to long-term recovery potential or future reuse scenarios.

BREEAM offers a more comprehensive approach, particularly through its integration of LCA and responsible sourcing criteria. This positions BREEAM closer to systemic material evaluation than LEED does. Nevertheless, BREEAM still approaches materials from an environmental performance perspective rather than a circularity perspective [6]. While BREEAM encourages the efficient use of materials and reduction of construction-phase waste, it falls short of quantifying dynamic material flows or assessing whether components can be disassembled and recovered at the end of their life [17]. Material traceability remains fragmented, and digital documentation systems capable of supporting long-term recovery, such as Material Passports or Digital Product Passports, are not incorporated into the framework.

DGNB stands out as the most advanced system in terms of life cycle thinking, due to its explicit integration of LCA and LCC as core components of its methodology. DGNB goes further than LEED and BREEAM in recognising the importance of adaptability, convertibility, and disassembly, elements that are closely aligned with CE principles [18]. However, DGNB also falls short of fully operationalising circularity. Despite addressing long-term design strategies and offering credits for reversibility, DGNB does not quantify the potential for material recirculation, long-term value retention, or multi-cycle reuse scenarios. Traceability tools, digital identities for materials, and data structures for managing building-level material stocks are similarly absent.

Viewed collectively, the three systems demonstrate the limitations of sustainability-driven certification approaches when applied to circularity assessment. LEED provides transparency; BREEAM provides environmental optimisation; DGNB provides life cycle thinking. Yet none of them measure circularity holistically or operationally [18].

None of the frameworks quantify how materials circulate across multiple life cycles, evaluate the conditions that support reuse and remanufacturing, incorporate digital documentation tools for material traceability, or assess regenerative outcomes. These systems were designed to reduce environmental harm, not to manage circular material flows.

Thus, although LEED, BREEAM, and DGNB contribute valuable structures for improving sustainability performance, they do not capture the systemic, regenerative, and multi-scalar nature of CE. Their methodologies remain grounded in environmental sustainability rather than in circularity, leaving significant gaps in material flow tracking, end-of-life modelling, and design strategies for value retention [17]. This comparative analysis highlights the need for new assessment methods or substantial adaptations of existing ones to better reflect CE requirements, integrate digital data infrastructures, and support the development of circular construction practices at scale.

## 5 Limitations of current tools

A comparative analysis of existing sustainability assessment frameworks, such as LEED, BREEAM, and DGNB, reveals structural limitations that hinder their ability to support a meaningful transition toward CE practices in the construction sector [19]. Although these systems have substantially advanced environmental performance evaluation and contributed to reducing operational and embodied impacts, their methodological foundations were not conceived with circularity in mind [18]. Consequently, they overlook several core dimensions required for the systemic transformation envisioned by CE principles.

A primary limitation is the absence of an explicit, comprehensive definition of circularity within these frameworks. While concepts such as resource efficiency, waste minimisation, and responsible sourcing are recurrent elements, none of the systems articulate circularity in terms of value retention, loop closure, design for disassembly, building components, or long-term material recirculation [6]. The lack of conceptual clarity leads to sustainability credits being misinterpreted as proxies for circularity, even though they pursue fundamentally different objectives.

Another critical gap is the absence of metrics capable of capturing material flow loops across multiple life cycles. Current tools do not quantify the ability of materials to circulate through reuse, repair, refurbishment, or remanufacturing pathways [17]. They also lack indicators for assessing component reversibility, selective deconstruction performance, recovery efficiency, or integration into secondary material markets. Instead, existing systems rely

*Table 1. Comparative overview of LEED, BREEAM, and DGNB with respect to circular economy principles*

| Criterion | LEED | BREEAM | DGNB |
|---|---|---|---|
| **Primary focus** | Environmental performance, transparency, waste reduction | Life-cycle environmental optimisation, responsible sourcing | Holistic sustainability with strong life-cycle integration (LCA + LCC) |
| **Integration of LCA** | Optional and limited in scope | Mandatory for several credits; more detailed | Central component of the methodology; highly developed |
| **Material efficiency** | Addresses waste management and recycled content | Emphasises efficient use of materials and construction-phase waste reduction | Integrated through LCA/LCC; includes resource efficiency |
| **Circularity definition** | Not defined; circularity treated indirectly | Not explicitly defined; partially integrated | Not fully defined, but closest to CE concepts due to adaptability and disassembly credits |
| **Design for Disassembly (DfD)** | Not evaluated | Limited or indirect consideration | Included as an optional criterion; strongest among the three |
| **Adaptability/flexibility** | Not systematically assessed | Addressed indirectly (e.g., durability, longevity) | Explicitly discussed as part of design strategies |
| **Material traceability** | Relies on EPDs and HPDs; no long-term tracking | EPDs used, but no persistent traceability | No integration of digital passports or long-term tracking |
| **Digital product data (MPs, DPPs)** | Not integrated | Not integrated | Not integrated, despite forward-looking potential |
| **End-of-life modelling** | Evaluates construction waste only | Limited modelling; static assumptions | Includes disassembly criteria, but without complete recovery modelling |
| **Value-retention strategies** | Not assessed | Not assessed | Acknowledged conceptually but not quantified |
| **Evaluation approach** | Static, project-level, one-time certification | Static; focuses on environmental optimisation | Life-cycle oriented but not dynamic across multiple cycles |
| **Overall alignment with CE** | Low | Moderate | Highest, but still partial and sustainability-driven |

on static, one-time indicators, such as recycled-content percentages or construction-phase waste diversion, that do not account for the dynamic, multi-cycle behaviour central to CE implementation.

The frameworks also fail to assess regenerative potential, which is essential for circularity in both technical and biological cycles [17]. While sustainability approaches prioritise impact reduction, circularity emphasises strategies that restore and regenerate systems. Yet, factors such as biogenic carbon cycling, ecosystem regeneration potential, renewable material replenishment, and positive environmental contributions are rarely incorporated into assessment methodologies.

A further limitation arises from insufficient integration of digitalisation trends. Existing systems do not adopt tools such as Material Passports, Digital Product Passports, digital building logbooks, or BIM-integrated circularity datasets, which are fundamental for long-term material traceability and future resource recovery [17]. Without such tools, buildings remain data-poor assets, and materials cannot be effectively tracked, documented, or reintroduced into technical cycles at the end of life.

Collectively, these limitations demonstrate that current sustainability assessment methods evaluate environmental performance rather than circularity [6]. They reduce harm but do not enable regenerative, multi-cycle material management. As a result, they fall short of capturing the systemic transformations required for CE implementation [17]. This confirms the methodological gaps identified in the broader literature and underscores the urgent need for new or adapted assessment tools capable of quantifying circularity, supporting material traceability, and enabling value retention across the entire building life cycle.

## 6 Identified gaps in measuring circularity

The theoretical analysis of existing assessment frameworks reveals several foundational limitations that prevent current systems from accurately reflecting the principles and operational requirements of the CE in the construction sector, as shown in Table 2 [17]. Although sustainability certification schemes have advanced environmental evaluation practices, they continue to be shaped by linear design assumptions and impact-reduction paradigms that are not compatible with multi-cycle, regenerative material flows. As a result, the measurement of circularity remains incomplete, fragmented, and conceptually inconsistent.

The first gap concerns the predominance of waste-centric metrics, which reduce circularity to construction-phase waste diversion, recycled content percentages, or general waste minimization efforts. While useful from a sustainability standpoint, these metrics do not capture the systemic nature of circularity, which depends on materials' ability to retain value across multiple life cycles [6]. This narrow focus risks equating circularity with recycling efficiency rather than recognising it as a broader regenerative strategy that prioritises reuse, durability, and high-value recirculation.

A second limitation arises from the static nature of current assessment frameworks. Most certification systems evaluate buildings at a single point in time, typically at design completion or project delivery, without considering how materials and components evolve over decades of use, maintenance, replacement, and eventual disassembly [6]. Because circularity is inherently temporal and requires ongoing monitoring of material condition, performance, and recoverability, static assessments cannot capture the dynamic pathways through which materials may circulate over extended lifespans.

A third gap relates to the lack of systematic material traceability. Circularity depends on robust, long-term documentation of material attributes, provenance, chemical composition, embodied impacts, and potential hazards. However, current tools do not incorporate digital mechanisms such as Material Passports (MPs), DPPs, or digital building logbooks [17]. Without persistent data structures, the possibility of recovering and reusing high-value materials is severely constrained, and buildings remain opaque repositories of materials that are difficult to reintroduce into technical cycles.

Fourth, existing assessment systems provide insufficient recognition of design-for-circularity strategies. Approaches such as modular design, reversible connections, adaptable spaces, and selective deconstruction are key to implementing CE [17]. Yet, most frameworks include these criteria only in optional, qualitative, or minimally weighted forms [6]. The absence of clear, quantifiable indicators for design decisions that influence future recoverability limits the integration of circular principles during early project stages, where they are most impactful.



*Table 2. Critical gaps in current circularity assessment within sustainability frameworks*

| Gap Identified | Description | Implications for Circularity |
|---|---|---|
| Waste-centric metrics | Focus on recycling rates, waste diversion, and construction-phase waste reduction, rather than on value retention or multi-cycle material loops. | Circularity becomes equated with waste management; high-value reuse, refurbishing, and remanufacturing remain unmeasured. |
| Static assessment frameworks | One-time evaluations at design or delivery stages that do not track materials over decades of use, replacement, or transformation. | Inability to assess material lifespan, future recoverability, or multi-cycle performance; the temporal dimension of circularity is ignored. |
| Limited material traceability | Absence of digital tools such as MPs, DPPs, or logbooks that provide persistent, structured material information. | Materials become impossible to recover at high value; lack of long-term documentation prevents technical loop closure. |
| Insufficient focus on design strategies | Weak or optional treatment of modularity, reversibility, adaptability, and design for disassembly. | Projects miss out on early-stage decisions that enable future reuse; design strategies central to CE are neither incentivised nor measured. |
| Absence of regeneration indicators | Lack of metrics for ecological regeneration, biogenic cycles, or positive environmental contributions. | Circularity remains limited to impact reduction; regenerative potential—key to CE—is not captured. |

Finally, the absence of regeneration-oriented indicators represents a significant conceptual gap. Circularity is not solely about closing loops; it also encompasses the capacity of built systems to regenerate biological cycles, renew biogenic materials, and create positive ecological outcomes [17]. Current frameworks prioritise impact reduction over value creation or regeneration, thereby overlooking opportunities for buildings to contribute to environmental restoration, renewable material cycles, and carbon sequestration.

Together, these gaps demonstrate that existing sustainability assessment tools measure sustainability rather than circularity [17]. They fail to capture the multi-dimensional, systemic, and regenerative ambitions of CE, underscoring the need for new or adapted metrics that support value retention, digital traceability, material adaptability, and long-term recirculation across the entire building lifecycle.

Building on the identified gaps, this study proposes a preliminary framework of circularity indicators to address the limitations of current assessment methods. The proposed indicators are structured across key dimensions, including material flow dynamics, design for circularity, value retention, digital traceability, and regenerative capacity. Table 3 presents this framework, intended as a conceptual foundation for developing more robust operational circularity assessment tools.

## 7 Discussion

The findings of this review show that current sustainability assessment systems, despite their contributions to reducing environmental impacts, do not adequately capture the systemic, regenerative, and multi-cycle principles that underpin the CE. The gaps identified across LEED, BREEAM, and DGNB reveal that these frameworks continue to operate within a linear paradigm, privileging environmental optimisation rather than long-term material value retention, regenerative design, and multi-scalar resource circulation. These limitations are not inherent to individual tools, but rather reflect the historical evolution of sustainability frameworks, most of which were conceived before the concept of CE thinking emerged as a guiding paradigm for the built environment.

The proposed indicator framework provides a structured response to the gaps identified in current assessment systems. By translating conceptual limitations into measurable dimensions, it enables a shift from descriptive sustainability assessment toward operational circularity evaluation. It addresses the absence of dynamic material flow metrics, long-term traceability mechanisms, and value-retention strategies highlighted in the previous sections. This transition is essential to move from assessing impacts to managing material performance across multiple life cycles.

Although certification systems incorporate critical sustainability dimensions such as waste minimisation, responsible sourcing, and life-cycle assessment, their methodologies are fundamentally impact-reduction-oriented. In contrast, circularity requires a structural redesign of how materials, components, and systems are conceived, used, managed, and recovered across successive life cycles. While sustainability seeks to "do less harm," circularity aims to preserve and regenerate value, keeping materials in technical or biological loops for as long as possible. This conceptual distinction underscores the need for new assessment approaches that go beyond environmental optimisation.

The introduction of circularity-oriented indicators also has important methodological implications. Unlike traditional sustainability metrics, which are often static and evaluated at a single point in time, the proposed indicators require dynamic data structures, longitudinal monitoring, and integration with digital tools such as Building Information Modelling (BIM), material passports, and digital product documentation systems. This suggests that future assessment frameworks must evolve from one-time certification schemes toward continuous, data-driven evaluation models capable of tracking material conditions, transformations, and recovery potential over time.

*Table 3. Critical gaps in current circularity assessment within sustainability frameworks*

| Dimension | Indicator | Description | Measurement approach |
|---|---|---|---|
| Material Flow | Recirculation Potential | Ability of materials to re-enter technical cycles | % reusable components, recovery scenarios |
| Design | Disassembly Index | Ease of separating components without damage | qualitative + connection typology |
| Value Retention | Residual Value | Economic value after first life cycle | LCC + secondary market estimation |
| Traceability | Material Transparency | Availability of digital material data | presence of MP/DPP |
| Adaptability | Functional Flexibility | Capacity to accommodate future uses | adaptability scoring |
| Regeneration | Biogenic Renewal Potential | Capacity to restore biological systems | % bio-based renewable materials |
| Material intensity | Desmaterialisation | Rate of reduction in material consumption per functional unit | Comparison between the baseline design and the optimised design |
| Waste generation | Waste Generation Rate | Amount of waste generated at the end of construction (m3/m2) | waste generation rate (mass or volume/building) |

To enable a genuine transition from linear to circular practices, the assessment of material performance must move beyond static, one-time evaluations and embrace continuous, data-driven monitoring over the building life cycle. Several enabling conditions emerge from the analysis:

The first requirement is the collaboration of multiple stakeholders, including industry practitioners, policymakers, certification bodies, researchers, and digital technology providers. Circularity cannot be implemented through isolated efforts; it requires harmonised definitions, consistent data structures, and aligned incentives across the entire value chain. Without coordination, adoption remains fragmented, limiting the scalability of circular practices and the development of cross-sectoral material loops.

A second enabler is the integration of digital tools for material tracking. Digital infrastructures, such as Material Passports, Digital Product Passports, BIM-embedded circularity datasets, and digital building logbooks, serve as foundational mechanisms for documenting material attributes over the long term. Without long-term traceability, even buildings designed for reuse or disassembly cannot achieve high-value recovery at the end of life. Embedding CE indicators into BIM workflows is therefore essential to operationalising circularity across design, procurement, and maintenance.

The third enabler concerns emerging business models that prioritise reuse, refurbishment, leasing, and product-as-a-service arrangements. Circularity cannot function effectively within traditional procurement and ownership structures. Instead, the construction sector must support reverse logistics networks, refurbishment centers, selective deconstruction services, and secondary material marketplaces. Assessment methods must evolve to capture these dimensions, evaluating not only material properties but the economic and organisational systems that support material circulation.

A fourth enabler is the development of regulatory frameworks that facilitate the recovery of materials. Current regulations often restrict the reuse of recovered components due to concerns about liability, safety requirements, or outdated standards. Circularity-aligned policies should promote performance-based approvals, establish quality standards for secondary materials, offer incentives for design for disassembly, and require mandatory documentation of material data. Assessment tools alone cannot shift practice unless they are supported by enabling regulations.

Table 4 highlights the differences between LEED, BREEAM, and DGNB in terms of their advantages, limitations, and opportunities for CE implementation. While DGNB provides the strongest methodological foundation, particularly through its life-cycle integration, none of the three systems offers a comprehensive assessment of circularity. Their limitations consistently relate to the absence of indicators for material recirculation potential, design reversibility, long-term value retention, and regenerative performance, as well as the insufficient incorporation of digital material traceability tools.

Overall, this analysis reinforces that current methods primarily evaluate sustainability, rather than circularity. They excel in reducing environmental burdens but fall short of capturing the dynamic, regenerative, and multi-cycle character of CE. Addressing these gaps requires a new generation of assessment tools that can quantify circularity, support digital traceability, and enable system-wide value retention throughout the entire building life cycle. Only through such tools will the construction sector be equipped to transition to a truly circular, regenerative built environment.

*Table 4. Advantages, limitations, and opportunities of LEED, BREEAM, and DGNB with respect to circular economy implementation*

| System | Advantages (Current Strengths) | Limitations (Gaps for Circularity) | Opportunities (Potential for CE Integration) |
|---|---|---|---|
| **LEED** | Global recognition and widespread adoption.<br><br>Strong emphasis on material transparency through EPDs, HPDs, and Declare labels.<br><br>Encourages the reuse of existing buildings and waste reduction during construction. | Does not evaluate design for disassembly, modularity, or reversibility.<br><br>No assessment of long-term material recovery potential.<br><br>Material traceability is limited to one-time product disclosures.<br><br>End-of-life scenarios are not considered. | Integration of Material Passports and Digital Product Passports.<br><br>Inclusion of indicators for recoverability, reuse potential, and multi-cycle performance.<br><br>Expansion of life cycle thinking beyond initial construction.<br><br>Development of circular credits in future LEED versions. |
| **BREEAM** | Strong integration of LCA and responsible sourcing.<br><br>Broader material-related coverage than LEED.<br><br>Emphasis on material efficiency and construction-phase waste management.<br><br>Encourages transparent supply chains. | • No modelling of material flows over multiple cycles.<br><br>Circularity-specific design strategies are not explicitly evaluated.<br><br>Traceability mechanisms are not integrated into long-term building documentation. | Potential to expand LCA to include circularity metrics (e.g., recirculation potential).<br><br>Integration of digital traceability tools, such as MPs and DPPs.<br><br>Development of credits on modularity, reusability, and component-level recovery. |

| | | | |
|---|---|---|---|
| | | End-of-life modelling is static and limited. | Strengthening of secondary material market incentives. |
| **DGNB** | Most advanced system regarding life-cycle integration (LCA + LCC).<br><br>Includes adaptability, convertibility, and disassembly criteria.<br><br>A holistic sustainability framework covers environmental, economic, and sociocultural aspects.<br><br>Encourages long-term performance and durability. | Material recirculation potential is not quantified.<br><br>Reuse pathways and secondary markets are not systematically evaluated.<br><br>Value-retention strategies are absent from the assessment criteria.<br><br>Digital identity and traceability tools are not incorporated. | Ideal candidate for integrating circularity-specific metrics.<br><br>A strong methodological foundation enables the adoption of digital material documentation systems.<br><br>Potential to link LCC with residual value forecasting and material recovery planning.<br><br>Expansion of disassembly and adaptability credits into mandatory criteria. |

As illustrated in Table 3, although DGNB demonstrates the most substantial methodological alignment with CE principles, none of the systems provides a complete framework for assessing multi-cycle material flows, value retention, or regenerative performance. This reinforces the need for new assessment mechanisms that support digital traceability, long-term design adaptability, and the systemic recirculation of materials.

## 8 Conclusions

This paper contributes to the theoretical development of circularity assessment in the construction sector by explicitly distinguishing sustainability-based evaluation from circularity-oriented assessment and by identifying the structural conditions required to operationalise circular economy principles within existing frameworks.

This study demonstrates that while current sustainability assessment frameworks, such as LEED, BREEAM, and DGNB, have played an essential role in guiding environmental performance improvements, they remain insufficient for evaluating or enabling CE practices in the construction sector. The analysis reveals that these tools were developed within a sustainability paradigm centred on impact reduction, resource efficiency, and transparency, but not on the regenerative, multi-cycle, and value-retention principles that define circularity.

Across all systems, circularity is often treated indirectly or superficially, with an excessive emphasis on waste minimization and recycled content, and limited consideration of material recirculation potential, design for disassembly, component adaptability, or long-term value retention. Material flow loops are not modelled, digital traceability is absent, and regenerative outcomes are not assessed. As a result, sustainability certifications continue to focus on measuring *environmental performance* rather than *circularity, revealing a conceptual and methodological gap that hinders* progress toward a circular built environment.

Closing this gap requires a fundamental rethinking of how buildings are evaluated, documented, and designed. The findings highlight four strategic enablers for future CE-oriented assessment methods: (1) multi-stakeholder collaboration to harmonise definitions, data structures, and incentives; (2) integration of digital tools such as Material Passports, Digital Product Passports, and BIM-based circularity datasets to enable long-term material traceability; (3) alignment with emerging business models that support reuse, refurbishment, and reverse logistics at scale; and (4) regulatory frameworks that facilitate material recovery, secondary-material markets, and performance-based acceptance of reused components.

Together, these elements suggest that future assessment frameworks must evolve beyond static certification models and adopt dynamic, data-rich, life-cycle-integrated methodologies capable of capturing the circulation, transformation, and regeneration of materials over time. Only by using new or substantially adapted tools will the construction sector operationalise circularity, optimise value retention, and support the transition toward a regenerative, resource-resilient built environment.

Ultimately, this review highlights the pressing need to develop indicators and digital infrastructures specific to circularity, enabling traceable, verifiable, and future-proof material cycles. Advancing circularity is not simply about extending existing sustainability metrics; it requires a paradigm shift that redefines how buildings are conceived, assessed, and managed throughout their life cycles. Such a shift is essential for achieving the systemic transformation needed to align the construction sector with the goals of a Circular Economy.

**Author Contributions**

Conceptualisation, G.C.C.P., M.R.M. and L.B.; methodology, G.C.C.P.; software, G.C.C.P.; formal analysis, G.C.C.P.; investigation, G.C.C.P.; resources, and L.B.; writing—original draft preparation, G.C.C.P. and M.R.M.; writing—review and editing, G.C.C.P., M.R.M. and L.B.; supervision, L.B; project administration, L.B.; funding acquisition, L.B. All authors have read and agreed to the published version of the manuscript.

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## Conflicts of Interest

The authors declare no conflicts of interest.

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