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Review of Circular Economy Research in the Construction Industry

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Abstract

This review synthesizes and critically evaluates current research on circular economy (CE) practices within the construction industry, a sector responsible for substantial resource consumption, waste generation, and greenhouse gas emissions. It examines how circular strategies such as refuse, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, and recover are being integrated into building design, material flows, project delivery, and end-of-life management. The paper systematically surveys peer-reviewed journal articles, conference papers, policy reports, and industry guidelines to identify dominant themes, methodological approaches, and empirical gaps. Findings show that most studies focus on recycling construction and demolition waste, design for disassembly, and life cycle assessment, while fewer works address circular business model innovation, social equity implications, and financial feasibility. Emerging digital enablers, including Building Information Modelling, digital twins, material passports, and blockchain-based traceability, are increasingly highlighted as tools for tracking materials, optimizing resource loops, and supporting scenario-based decision-making. However, fragmented supply chains, limited and inconsistent data, unclear material ownership, weak regulatory incentives, and cultural resistance among project stakeholders continue to constrain large-scale CE implementation. The review also identifies a strong geographic imbalance, with evidence concentrated in Europe and China, and comparatively limited studies from Africa, Latin America, and other developing regions where rapid urbanisation and infrastructure deficits intensify resource pressures. Overall, the article argues that future research must move beyond isolated technical solutions toward systems thinking that aligns design practice, procurement strategies, regulations, financial instruments, and user behaviour. Priority areas include robust quantitative metrics for circular performance, scalable circular business and procurement models, inclusive policy instruments, skills development, and cross-sector collaboration platforms. By consolidating existing knowledge and highlighting critical research frontiers, this review supports researchers, practitioners, educators, and policymakers seeking to accelerate the transition from linear “take–make–dispose” patterns to regenerative, low-carbon, and resource-efficient construction systems. In practical terms, the findings underline the need for integrated governance frameworks, strong client leadership, and performance-based procurement standards that reward circular outcomes throughout the project life cycle, from concept design to deconstruction and secondary material markets.

Keywords: Circular Economy, Construction Industry, Construction and Demolition Waste, Sustainable Construction, Building Information Modelling, Material Passports, Digital Twins, Life Cycle Assessment

1. Introduction

The construction industry is one of the most resource-intensive and environmentally impactful sectors of the global economy. It consumes vast quantities of raw materials, water, and energy, while generating significant volumes of construction and demolition waste that often end up in landfills. The production and use of construction materials, particularly cement and steel, contribute substantially to greenhouse gas emissions and the depletion of natural resources.

Urbanisation, infrastructure expansion, and the replacement of aging building stock continue to intensify these pressures, raising urgent questions about how to decouple construction activity from environmental degradation and move towards more sustainable patterns of development (Leising, Quist & Bocken, 2018, Pomponi & Moncaster, 2017).

In response to these challenges, the circular economy (CE) has emerged as a promising paradigm for rethinking how buildings and infrastructure are designed, delivered, used, and eventually deconstructed. Rather than following a linear “take–make–dispose” model, circular approaches emphasise slowing, closing, and narrowing resource loops through strategies such as reuse, repair, remanufacturing, and high-quality recycling. Applied to the built environment, CE principles encourage design for adaptability and disassembly, long-life building components, and the creation of secondary material markets. They also call for new business models, governance arrangements, and digital tools that can support traceability, performance optimisation, and more collaborative value chains (Ghisellini, Ripa & Ulgiati, 2018, Heshmati, 2017).

Over the past decade, research on circularity in construction has expanded rapidly, spanning disciplines such as engineering, architecture, environmental science, business, and policy studies. Despite this growth, the literature remains fragmented across different life cycle stages, regional contexts, and conceptual frameworks. Many studies focus on specific technical solutions, material streams, or project case studies, making it difficult to form an integrated picture of how CE is being interpreted, operationalised, and evaluated within the sector. A comprehensive review is therefore needed to consolidate existing knowledge, identify converging themes and persistent blind spots, and clarify the extent to which current research supports large-scale transitions towards circular construction (Winans, Kendall & Deng, 2017, Su, *et al*., 2013).

The aim of this review is to critically examine and synthesise contemporary circular economy research in the construction industry, with a focus on how circular strategies are conceptualised, implemented, and assessed across the building life cycle. The specific objectives are to map the main thematic areas and methodological approaches, to identify key drivers and barriers reported in the literature, and to highlight emerging tools and practices that enable circular construction. The review is guided by the following questions: How is the circular economy defined and framed within construction research (Mabo, Swar & Aghili, 2018)? What circular strategies and interventions are most frequently studied, and at which life cycle stages? Which technological, organisational, and policy enablers or obstacles are most prominent? The scope encompasses peer-reviewed articles, conference papers, and selected policy and industry reports on CE in construction, with an emphasis on recent contributions that address design, materials, project delivery, end-of-life management, and supporting digital technologies (Nasir, *et al*., 2017, Ormazabal, *et al*., 2018).

2. Methodology

The review adopted a systematic literature review design combined with narrative synthesis to map and critically analyse circular economy research in the construction industry. The process began with clarification of the review questions, which focused on how circular economy principles are defined and operationalised in construction, which life cycle strategies are most frequently examined, what digital and organisational enablers are reported, and where key gaps remain. On this basis, an a priori protocol was developed that defined the scope of the review as peer reviewed and high quality grey literature that explicitly addresses circular economy, resource efficiency or sustainability in relation to the built environment, together with a small set of conceptual and technological papers that inform digital, business model and governance aspects of circular construction.

Search strings were constructed by combining keywords such as “circular economy”, “construction”, “built environment”, “construction and demolition waste”, “adaptable buildings”, “building information modelling”, “digital construction”, “circular business models”, “resource efficient construction”, and “sustainable building design”. These were applied using Boolean operators across major databases, including Scopus, Web of Science, ScienceDirect and Google Scholar. In parallel, targeted searches were carried out for key reports and handbooks from policy and industry bodies that are widely cited in circular economy debates. Seminal works on circular economy and the built environment, such as Adams *et al*. (2017), Behera *et al*. (2014), Ghisellini *et al*. (2018), Heshmati (2017), Mangialardo and Micelli (2018), Nasir *et al*. (2017), Ness and Xing (2017), Pomponi and Moncaster (2017), Su *et al*. (2013), Velenturf *et al*. (2019), Walmsley *et al*. (2019), Winans *et al*. (2017) and related frameworks on adaptability, sustainable design and regenerative built environments were used as seed articles for backward and forward snowballing. This iterative process ensured that the final corpus captured both early conceptual contributions and more recent empirical and methodological developments.

The initial set of records retrieved from the databases was exported and duplicates removed. Titles and abstracts were then screened against predefined inclusion and exclusion criteria. Studies were included if they: focused on construction, buildings or the built environment; addressed one or more circular economy strategies or closely related concepts such as design for disassembly, adaptability, resource efficient construction or circular business models; and were published in English. Studies that treated circular economy only tangentially, or focused solely on unrelated sectors without transferable insights, were excluded at this stage. Full text screening was then conducted to confirm eligibility and to ensure that each selected article contained substantive discussion of circular strategies, metrics, barriers, drivers or enabling technologies relevant to construction.

In addition to this core set, a purposive sample of cross cutting literature was incorporated to support the analysis of digital and organisational enablers and indicator frameworks. These included works on circular business models, complex value assessment and circular indicators (for example Geissdoerfer *et al*., Iacovidou *et al*., Moraga *et al*.), digital ecosystems and big data architectures (for example Asch *et al*., Briscoe *et al*., Demchenko *et al*., Kitchin), platform based and AI enabled smart building ecosystems and construction technology ecosystems (for example Aksenova *et al*., Blanco *et al*., Woodhead *et al*., Xu *et al*.), and broader discussions of sustainability, resilience and regenerative paradigms in the built environment (for example Akadiri *et al*., Brandon and Lombardi, Du Plessis, Gosling *et al*., Heidrich *et al*., Kibert, Opoku). These sources were identified through keyword searches and expert judgement rather than strict sector filters, and were included where they offered transferable concepts or frameworks for circular construction. The final sample comprised 100 sources, corresponding to the reference list provided.

Data extraction followed a structured template. For each source, bibliographic details, geographical focus, building type or construction context, and methodological approach were recorded. Substantive information was then coded on circular economy definitions and conceptualisations, life cycle stages addressed (design, materials, construction, operation, end of life), specific circular strategies examined (for example reuse, remanufacturing, high quality recycling, circular supply chains, circular business models), digital and technological tools (for example BIM, digital twins, material passports, sensor networks, decision support systems), and reported barriers, drivers and policy instruments. For works on indicators and frameworks, the types of metrics proposed, system boundaries, and dimensions covered (environmental, economic, social, governance) were captured. For cross sector digital and AI papers, relevant concepts such as data architectures, platform governance, algorithmic decision support and risk management were extracted where they could inform the discussion of digital enablers in construction.

Coding combined deductive and inductive elements. Deductively, an initial coding frame was derived from the review questions and from existing frameworks for circular economy in the built environment. This included codes for R strategies, life cycle stages, actor groups, enabling technologies, and types of barriers and drivers. Inductively, new codes were added as recurring patterns, novel concepts or underexplored themes emerged from the material, for example specific circular tourism and SME experiences that illustrate organisational and cultural dimensions, or emerging links between circular construction and broader urban sustainability transitions. Coding was carried out using spreadsheets and simple qualitative analysis software to allow cross tabulation of themes by time period, region and method.

The synthesis stage used a concept centric approach. Rather than summarising each article in isolation, evidence was clustered around key themes that align with the structure of the review: conceptual foundations, methodological approaches, circular strategies across the life cycle, digital and technological enablers, barriers and drivers, and research gaps and future directions. Within each theme, findings from different methodological traditions were compared, and convergences or divergences in definitions, methods and reported outcomes were highlighted. Where appropriate, descriptive statistics on the distribution of studies by year, geography, method or focus area were used to illustrate trends, although the primary mode of synthesis remained narrative and interpretive. Particular attention was paid to how insights from adjacent fields such as circular business models, digital ecosystems, big data and AI could inform emerging research agendas on circular construction.

Throughout the process, measures were taken to enhance transparency and rigour. The search strings, databases and inclusion criteria were documented to allow replication. Decisions made during screening, particularly for borderline cases, were recorded, and reasoning for including non construction sources was explicitly linked to their conceptual contribution. The coding frame was refined iteratively, with sample checks to ensure consistent application of codes across the corpus. The resulting methodology provides a structured yet flexible basis for integrating heterogeneous literature on circular economy and construction and for drawing robust conclusions about the current state of knowledge and future research needs.

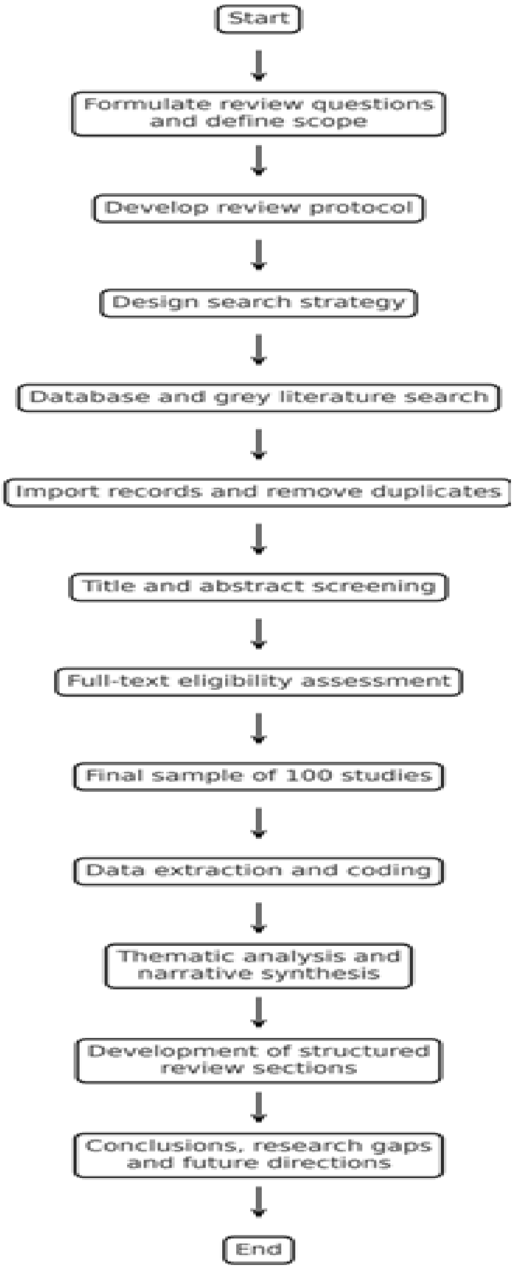

Fig 1: Flowchart of the study methodology

2.1. Conceptual Foundations of the Circular Economy in Construction

The conceptual foundations of the circular economy in the construction industry rest on reimagining how resources flow through the built environment. At its core, the circular economy is an economic and industrial model that seeks to maintain the value of materials, components, and products for as long as possible by slowing, closing, and narrowing resource loops. In contrast to traditional linear systems that extract resources, transform them into products, and dispose of them as waste, circular systems prioritise regeneration, restorative design, and long term stewardship of assets. Within construction, this means viewing buildings not as static end products but as dynamic material banks whose components can be adapted, reused, or reintegrated into future projects (Adams, *et al*., 2017, Ivanova, *et al*., 2016).

Key principles of the circular economy are often expressed through the hierarchy of "R strategies," which outline different ways to reduce resource use and waste. These typically include refuse and rethink, which challenge the need for resource intensive solutions in the first place, and reduce, which focuses on material efficiency and lightweight design. Reuse, repair, refurbish, and remanufacture aim to extend the life of products and components by preserving their form and function, while repurpose and recycle seek to recover value from materials that can no longer serve their original role. At the lowest level, recover refers to energy recovery from residual waste that cannot be feasibly recycled (Akadiri, Chinyio & Olomolaiye, 2012, Sfakianaki, 2015). In construction, these strategies translate into practices such as design for adaptability and disassembly, the use of modular systems, selective demolition, high quality recycling of construction and demolition waste, and the creation of secondary material markets.

Understanding the difference between linear and circular models in the built environment is essential for interpreting current research. The linear "take, make, dispose" model treats buildings as one way sinks for materials and energy. Raw materials are extracted, processed into products, assembled into structures, used for a limited lifespan, and eventually demolished with significant waste streams. Externalities such as environmental degradation and greenhouse gas emissions are rarely accounted for in design and procurement decisions. By contrast, a circular model views the built environment as part of a broader socio technical system in which materials circulate through multiple lifecycles (Guo, *et al*., 2019, Huang, *et al*., 2018). Buildings are designed as long lived assets whose components can be replaced, upgraded, or reconfigured over time, and whose end of life is managed through deconstruction and organised material recovery rather than indiscriminate demolition. Ownership and business models may also change, with a shift from selling products to providing services such as performance based building contracts, leasing of components, or take back schemes.

These differences have implications for how researchers define system boundaries and interpret circularity. Several theoretical frameworks structure circular economy research in construction. Industrial ecology provides one influential lens, emphasising the analogy between industrial systems and natural ecosystems and promoting tools such as material flow analysis to track resource stocks and flows (Hampson, Kraatz & Sanchez, 2014, Roos, 2014). Life cycle thinking and life cycle assessment frameworks extend this perspective by evaluating environmental impacts from cradle to grave, or in circular contexts from cradle to cradle, across extraction, manufacturing, use, and end of life phases. These frameworks encourage designers and policymakers to consider upstream and downstream consequences of material choices and construction methods, rather than focusing only on the operational performance of buildings. Figure 2 shows linear versus circular economy diagram presented by Unterfrauner, *et al*., 2017.

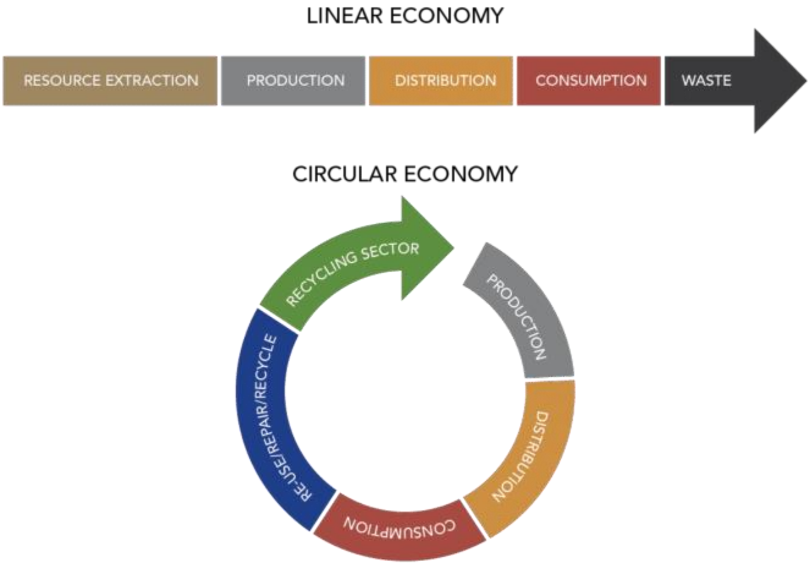

Fig 2: Linear versus circular economy (Unterfrauner, *et al*., 2017)

Another strand of theory draws on systems thinking and socio technical transition frameworks. Approaches such as the multi level perspective on transitions or the concept of socio technical regimes highlight that circular construction is not only a technical challenge but also a cultural, organisational, and institutional one. They emphasise that design practices, regulations, supply chains, financial structures, and user behaviours are deeply interlinked, and that significant change requires coordinated shifts at multiple levels. In this view, pilot projects and living laboratories act as niches where novel circular practices can be tested and scaled, while existing norms and regulations may either support or constrain their diffusion (Heyes, *et al*., 2018, Williams, *et al*., 2018).

Urban metabolism and stock based approaches also contribute to the conceptual toolkit. Urban metabolism models conceptualise cities and regions as organisms that consume resources and generate waste, providing a way to quantify the inflows, outflows, and accumulation of construction materials over time. Building stock modelling and dynamic material flow analysis focus specifically on the quantities, types, and age profiles of materials embedded in existing buildings and infrastructure. These approaches support the idea of buildings as material banks and help identify future waves of construction and demolition waste that could be channelled into circular loops if appropriate policies and technologies are in place (Bicket, *et al*., 2014, Mendoza, *et al*., 2017).

Choices about system boundaries are particularly significant in circular economy research on construction. Some studies adopt narrow boundaries focused on individual products, components, or buildings, while others take a broader perspective that includes regional supply chains, secondary material markets, and user behaviours. Temporal boundaries also vary, from short term assessments of specific projects to long term analyses of building stocks across several decades (Kapsalis, Kyriakopoulos & Aravossis, 2019, Moraga, *et al*., 2019). The way boundaries are defined affects which circular strategies appear most effective and which trade offs are captured, for example between embodied impacts at the production stage and operational energy use during the use phase. Conceptual clarity about these boundaries is therefore essential to ensure that findings from different studies are comparable and that claims about circularity are not overstated. Figure 3 shows principles of circular economy applied in the construction industry presented by Mangialardo & Micelli, 2018.

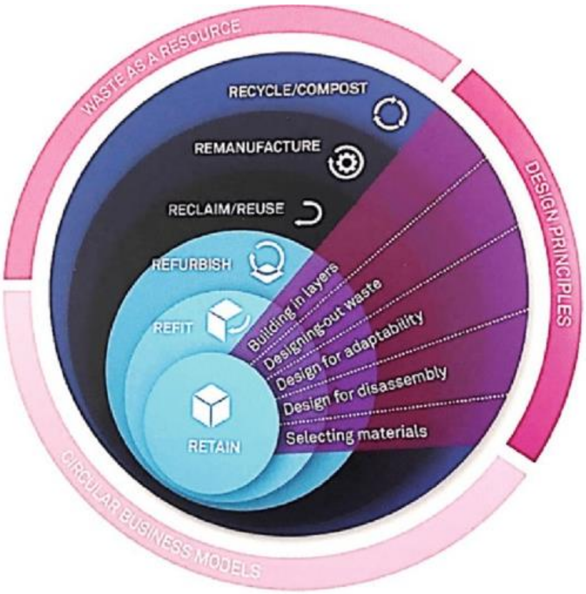

Fig 3: Principles of circular economy applied in the construction industry (Mangialardo & Micelli, 2018).

Overall, the conceptual foundations of the circular economy in construction are characterised by a shift from linear, short term thinking towards integrated, long term, system oriented perspectives. Definitions centred on maintaining value and closing resource loops, the operationalisation of R strategies, and the use of theoretical frameworks such as industrial ecology, life cycle assessment, systems thinking, and urban metabolism provide a common language for researchers and practitioners. At the same time, there remains variation in how circular economy concepts are interpreted and applied across studies (Velenturf, *et al*., 2019, Walmsley, *et al*., 2019). Some focus primarily on waste reduction and recycling, while others emphasise business model innovation, design for adaptability, or societal change. Clarifying these conceptual foundations is crucial for interpreting the growing body of literature, identifying convergence and divergence in definitions, and guiding future research that can support a genuinely circular built environment.

2.2. Methodological Approaches in Circular Economy Construction Research

Methodological approaches in circular economy research on the construction industry are highly diverse, reflecting the complexity of the built environment and the multi-dimensional nature of circularity. Researchers draw on a wide spectrum of study types, ranging from systematic reviews that synthesise existing evidence to detailed case studies of individual projects, modelling exercises that explore alternative futures, and surveys that capture stakeholder perceptions and behaviours. Systematic and scoping reviews have become increasingly common as the body of literature expands, using transparent search strategies, inclusion and exclusion criteria, and structured appraisal tools to map how circular concepts are defined, which strategies are most studied, and where gaps persist (Iacovidou, *et al*., 2017, Nambiar, 2019). These reviews provide meta-level insights but are constrained by the quality, heterogeneity, and reporting standards of the underlying studies, and they often reveal inconsistent use of terminology and indicators across the field.

Case studies remain a central methodological choice, especially when examining innovative projects that experiment with design for disassembly, material reuse, or new business models such as product-service systems. Single case studies allow in-depth exploration of technical solutions, organisational arrangements, and decision processes, often combining qualitative interviews, document analysis, and technical performance data. Multiple or comparative case studies extend this logic by comparing different projects, firms, or regions, highlighting contextual influences on the adoption of circular strategies. However, case study research often struggles with generalisability; the findings are rich but situated, and sample sizes are usually small, which makes it difficult to derive widely applicable conclusions without supplementary quantitative analysis (Manniche, *et al*., 2017, Mylan, Holmes & Paddock, 2016).

Modelling studies constitute another important methodological strand. These include life cycle assessment (LCA) models that quantify environmental impacts across the life cycle of buildings or materials, material flow analysis (MFA) and stock-flow models that track the movement and accumulation of construction materials over time, and optimisation or scenario models that explore trade-offs between design choices, cost, and environmental performance. Some studies use system dynamics or agent-based modelling to simulate the behaviour of stakeholders and the diffusion of circular practices under different policy or market conditions. These modelling approaches provide powerful tools for exploring “what-if” scenarios and identifying leverage points, but they depend heavily on data quality, boundary choices, assumptions about behaviour, and the availability of reliable emission factors and cost parameters (Jackson, Lederwasch & Giurco, 2014, Perey, *et al*., 2018).

Survey-based research and stakeholder studies complement these technical approaches by investigating the attitudes, awareness, and decision drivers of architects, engineers, contractors, clients, policymakers, and end-users. Structured questionnaires, semi-structured interviews, Delphi studies, and focus groups are used to identify perceived barriers and drivers, assess readiness for circular practices, and prioritise policy measures or design strategies. These methods generate valuable insights into socio-cultural and organisational dimensions of circularity that are not captured by purely technical models. Yet they are often limited by sampling biases, low response rates, self-reported data, and difficulties in linking perceptions directly to actual changes in material flows or environmental performance (Fratini, Georg & Jørgensen, 2019, Linder, 2017).

The diversity of study types is mirrored in the variety of data sources, metrics, and analytical tools deployed. Primary data often come from bills of quantities, design drawings, BIM models, site measurements, waste records, and interviews with project participants. Secondary data are drawn from environmental product declarations, national statistics, industry databases, and generic LCA databases. Environmental metrics commonly include global warming potential, embodied energy, resource depletion, waste generation, and sometimes broader impact categories such as acidification or eutrophication (Ness & Xing, 2017, Rios, 2018). Circularity-specific indicators are increasingly used, such as material circularity indicators, recycling and reuse rates, proportion of secondary materials, and indicators for service life extension or adaptability. Economic metrics, including life cycle costs, net present value, and payback periods, are also deployed to assess financial feasibility, while social indicators, though less frequent, may cover employment, health and safety, or community benefits. Figure 4 shows the circular economy presented by Geissdoerfer, *et al*., 2020.

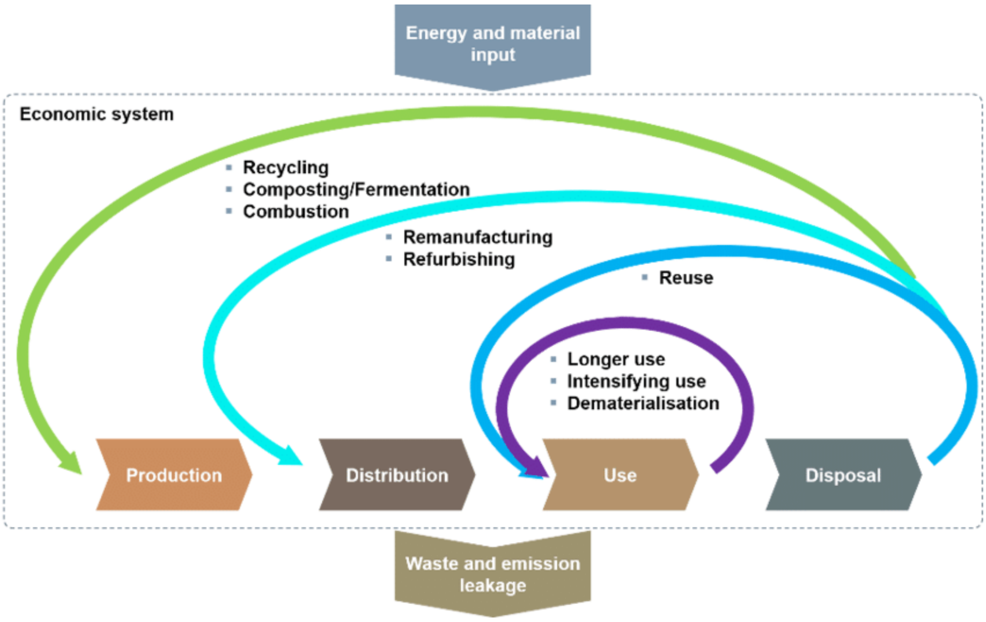

Fig 4: The circular economy (Geissdoerfer, *et al*., 2020)

Analytical tools range from specialised LCA software to spreadsheet models, MFA tools, statistical packages, and multi-criteria decision analysis frameworks. Building Information Modelling is increasingly integrated with LCA and material inventorying, allowing researchers to simulate design options and quantify their circular performance during early design stages. GIS tools are sometimes applied to analyse spatial patterns of material stocks and potential hubs for secondary material markets. Cluster analysis, regression models, and structural equation modelling are used to explore relationships between variables in survey data, while multi-criteria techniques support the ranking of design alternatives or policy options based on environmental, economic, and social criteria. The choice of tools and metrics significantly shapes the conclusions of each study, especially when system boundaries, functional units, and impact categories differ (Carter, *et al*., 2015, Pomponi & Moncaster, 2017).

Each methodological approach has particular strengths and limitations. Systematic reviews provide transparency and breadth but may oversimplify complex context-specific findings. Case studies offer depth and rich contextual insights but are often criticised for limited generalisability and potential researcher bias. Modelling studies can explore future scenarios and quantify impacts with precision, yet they risk creating an illusion of certainty when input data are incomplete or assumptions are not clearly reported. Surveys and qualitative studies capture human and institutional dimensions that are crucial for implementation, but they rarely provide direct evidence of material and emission reductions. Across these approaches, reproducibility and comparability remain significant challenges because of inconsistent indicator sets, varied data sources, and divergent boundary choices (Béné, *et al*., 2014, Buckman, Mayfield & BM Beck, 2014).

Emerging methodological trends attempt to address some of these shortcomings by combining and hybridising methods. Mixed-methods designs that integrate quantitative modelling with qualitative stakeholder research are becoming more common, enabling researchers to connect technical potential with organisational realities. BIM-LCA integration and digital twins allow dynamic updating of environmental and circularity metrics as design and construction progress, bridging the gap between ex-ante assessment and real-time performance monitoring. Dynamic LCA and stock-flow models introduce temporal dimensions, capturing how material stocks and flows evolve over decades and how different renovation or demolition strategies affect future circular opportunities (Andrade & Bragança, 2019, Hassler & Kohler, 2014). There is also a gradual shift towards more standardised circularity indicators and benchmarking frameworks, although consensus has not yet been fully achieved.

Another notable trend is the increasing use of participatory and action research approaches, such as living labs and co-creation workshops, where researchers collaborate directly with practitioners, public authorities, and communities to design, implement, and monitor circular interventions. These approaches generate practice-relevant knowledge and can accelerate learning across projects, while also highlighting institutional and governance constraints that might otherwise be overlooked. At the same time, they are resource intensive, context dependent, and sometimes difficult to document in ways that meet conventional academic standards (Gijsbers & Lichtenberg, 2014, Pinder, *et al*., 2017).

Overall, methodological innovation in circular economy construction research is moving towards more integrated, multi-scale, and transdisciplinary approaches. The future methodological agenda is likely to emphasise transparent reporting of assumptions and boundaries, open data and model sharing, robust sensitivity and uncertainty analyses, and stronger connections between technical performance metrics and socio-economic outcomes. By refining and combining existing methods, and by developing new tools that reflect the complex reality of the built environment, researchers can provide more reliable, comparable, and actionable evidence to guide the transition towards a truly circular construction sector.

2.3. Circular Strategies across the Construction Life Cycle

Circular strategies across the construction life cycle seek to intervene at each stage of a building's existence, from early concept design to end of life, in order to maintain material value, extend service life, and minimise waste. A central focus in the literature is on design for adaptability, disassembly, and reuse. Adaptability refers to the capacity of buildings and components to accommodate changing functions, technologies, and user needs without major structural interventions. Researchers describe strategies such as flexible floor plans, generous floor-to-ceiling heights, non load bearing partitions, and accessible service zones that can be modified without destroying the main structure. Design for disassembly extends this thinking by ensuring that connections between elements are reversible and that components can be separated without damage (Heidrich, *et al*., 2017, Schmidt III, *et al*., 2010). This is often achieved through mechanical fixings rather than glues, standardised connection details, and clear documentation of assembly logic. When such principles are applied, components such as facade panels, structural members, and interior fittings can be recovered and reused in future projects, rather than being crushed into low grade aggregates.

Design for reuse is closely linked to the idea of buildings as material banks. Through careful specification, documentation, and tracking of components, researchers propose that buildings can serve as repositories of high quality materials that retain value beyond the initial service life of the structure. Studies explore methods for marking components, using digital material passports, and integrating these with Building Information Modelling so that future owners and contractors can quickly identify elements suitable for reuse. The conceptual shift from permanent assembly to reversible configuration is a recurring theme, although practical challenges remain, including the need for early commitment from clients, coordination across disciplines, and alignment with building codes and insurance requirements (Eber, 2019, Gosling, *et al*., 2013).

Material selection, prefabrication, and modular construction represent another set of circular strategies that operate during design and construction. Literature on material selection emphasises choosing materials with low embodied carbon, renewable or recycled content, and high potential for reuse or high quality recycling. Bio based materials such as timber, engineered wood products, and biocomposites are often highlighted, alongside recycled metals, reclaimed bricks, and low clinker cements. Researchers examine trade offs between durability, maintainability, and circular potential, noting that a material that is recyclable in theory may not be recovered in practice if it is bonded in complex composites or contaminated by finishes (Chen, *et al*., 2019, Xu, *et al*., 2019). The emphasis is therefore not only on material properties but also on how materials are combined and detailed.

Prefabrication and modular construction are frequently presented as enablers of circularity because they encourage standardisation, reduce waste on site, and facilitate disassembly and reuse. Off site manufacturing allows components to be produced with tight tolerances, efficient material use, and controlled quality, which can enhance the durability and reusability of elements. Modular systems, whether volumetric modules or panelised elements, lend themselves to rearrangement, replacement, and relocation (Bi, *et al*., 2019, Wang & Srinivasan, 2017). For example, a modular office building may be reconfigured to accommodate new layouts or moved to a different site, reducing the need for new construction. Case studies report significant reductions in construction waste and improved material recovery potential when modular designs are combined with reversible connections and clear assembly documentation.

At the same time, researchers recognise that prefabrication and modularity do not guarantee circular outcomes. The benefits depend on design choices, business models, and organisational practices. If modules are designed for a single project with bespoke details, their reuse potential may be limited. If supply chains are not organised to take back components, valuable materials may still end up in landfills. Economic and contractual arrangements need to support long term stewardship, such as leasing of components, producer responsibility schemes, or service based models in which manufacturers retain ownership and responsibility for maintenance and end of life management (Baryannis, *et al*., 2019, Kaartemo & Helkkula, 2018).

End of life strategies complete the circular life cycle and receive substantial attention in construction research. Deconstruction, as distinct from conventional demolition, is a process of carefully disassembling buildings to recover components and materials for reuse or high quality recycling. Studies highlight techniques such as selective dismantling, on site sorting, and the use of specialised tools and logistics planning to maximise recovery rates (Li, *et al*., 2017, Lu, Chen & Zheng, 2012). Deconstruction is most effective when buildings were designed with it in mind, but even in existing stock, targeted interventions can recover valuable elements such as steel beams, timber joists, and facade units. Policy measures like landfill taxes, subsidies for deconstruction training, and procurement requirements can influence whether deconstruction becomes a viable alternative to demolition.

Remanufacturing is another circular strategy that aims to return used components to a like new condition. In the construction context, this may involve refurbishing windows, doors, raised floor systems, or structural steel elements.

Researchers explore technical processes to assess residual performance, remove contaminants, repair damage, and recertify components for new applications. Remanufacturing has the potential to preserve the embodied energy and value of products while reducing environmental impacts compared to producing new items. However, it faces challenges related to quality assurance, standardisation, liability, and matching supply with demand (Mak & Pichika, 2019, Turner-Skoff & Cavender, 2019). Clear standards and certification mechanisms are needed to give designers and clients confidence in remanufactured products.

Recycling remains the most widely implemented circular strategy at end of life, particularly for mineral construction and demolition waste. Concrete and masonry are often crushed for use as aggregates, metals are recovered and reprocessed, and some fractions of glass, wood, and plastics are recycled. Research emphasises the difference between low grade downcycling, where materials are used for less demanding applications such as road sub base, and closed loop or high grade recycling, where materials retain similar performance characteristics (Du Plessis, 2012, Hwang & Tan, 2012). Technologies such as advanced sorting, selective demolition, and improved processing can increase the quality of secondary materials, but systemic barriers remain, including contamination, lack of standard specifications for recycled content, and conservative attitudes among designers and regulators.

Secondary material markets are critical to making deconstruction, remanufacturing, and recycling economically viable. Studies describe the development of physical and digital marketplaces where reclaimed components and recycled materials can be traded. Digital platforms that provide information on available materials, their quantities, locations, and performance characteristics are gaining attention, often linked to material passports and regional material flow data. Successful secondary markets depend on reliable supply, consistent quality, competitive pricing, and supportive regulations that allow and encourage the use of secondary materials in new construction (Kibert, 2016, Portney, 2013). Public procurement can play a significant role by specifying minimum levels of recycled or reclaimed content and by prioritising projects that demonstrate circular performance.

Taken together, circular strategies across the construction life cycle illustrate that no single intervention is sufficient on its own. Design for adaptability and disassembly sets the stage for future reuse. Thoughtful material selection and modular prefabrication enhance the technical feasibility of recovery. Deconstruction, remanufacturing, and recycling practices, supported by robust secondary markets, ensure that end of life processes close the loop rather than creating new waste streams. The literature underlines that these strategies must be integrated into coherent project delivery models, supported by aligned regulations, financial incentives, and cultural shifts within the industry. When considered as a whole, life cycle oriented circular strategies offer a pathway to significantly reduce resource use and emissions while creating new value propositions for stakeholders in the built environment.

2.4. Digital and Technological Enablers of Circular Construction

Digital and technological enablers are playing an increasingly central role in operationalising circular economy principles in the construction industry. Among these, Building Information Modelling, digital twins, and material passports are frequently highlighted as core pillars of a digital infrastructure that can support circular design, construction, and end of life strategies. Building Information Modelling (BIM) provides a shared digital representation of the physical and functional characteristics of a building. It allows stakeholders to embed and access information about geometry, quantities, material specifications, performance attributes, and maintenance requirements within a single, coordinated model (Ness & Xing, 2017, Opoku, 2016). In the context of circular construction, BIM is used to track material quantities and qualities, assess environmental impacts through integrated life cycle assessment modules, and simulate design alternatives that improve adaptability, disassembly, and reuse potential. Researchers show how BIM-based workflows can support early design decisions by making visible the implications of material choices, connection details, and modular layouts for future recovery and recycling.

Digital twins extend the logic of BIM beyond static design models to dynamic, data-rich representations of buildings and infrastructure in use. A digital twin links virtual models with real-time or near real-time data from sensors, monitoring systems, and building management platforms. This connection enables continuous tracking of performance, deterioration, and maintenance actions. From a circular perspective, digital twins can inform strategies to extend service life, optimise maintenance schedules, and plan interventions that preserve component value. For example, condition data from sensors can identify when components are approaching the end of their functional life and can be scheduled for refurbishment or replacement in a way that maximises reuse potential. Over longer time horizons, digital twins may also provide detailed inventories of the materials embedded in building stocks, which can feed into regional planning for future deconstruction and material recovery (Brandon & Lombardi, 2010, Opoku, 2019).

Material passports complement these digital models by providing structured documentation of the properties, origins, and reuse potential of specific products and components. A material passport typically contains information on material composition, hazardous substances, mechanical and thermal performance, maintenance history, and possible reuse or recycling pathways. Researchers describe how passports can be attached to elements within BIM models, enabling a layered understanding of the circular value of each component. When buildings are renovated or deconstructed, these passports can guide decisions on whether components are suitable for direct reuse, remanufacturing, or recycling, and can support quality assurance in secondary material markets (Comes, *et al*., 2011, Opoku, 2015). Together, BIM, digital twins, and material passports form an emerging digital ecosystem that makes circular strategies more visible, measurable, and manageable throughout the building life cycle.

Beyond these core tools, blockchain and other digital technologies are increasingly explored for their potential to enhance traceability and data management in circular construction. Blockchain, as a distributed ledger technology, can provide tamper-resistant records of transactions, ownership, and material flows. In circular economy research, it is proposed as a means to record the provenance of materials and components, verify compliance with environmental and social standards, and manage complex ownership arrangements that arise in product-service systems or leasing models (Howell, Windahl & Seidel, 2010, Pellerin & Perrier, 2019). For example, blockchain-based smart contracts can automate the execution of take-back agreements between manufacturers and clients, triggering collection and remanufacturing processes when components reach predefined conditions. They can also support trust in secondary material markets by providing reliable histories of previous uses, maintenance, and certifications.

Other digital tools contribute to traceability and data management in complementary ways. Internet of Things devices and sensor networks can monitor conditions such as temperature, humidity, occupancy, and structural health, feeding data into digital twins and facility management systems. Geographic Information Systems support spatial analysis of material stocks and flows at urban or regional scales. Cloud-based databases and platforms enable the storage, sharing, and updating of material passports, environmental product declarations, and project data among multiple stakeholders (Ika, Diallo & Thuillier, 2010, Webber, *et al*., 2019). Data analytics and machine learning techniques are used to identify patterns in material use, predict maintenance needs, and optimise logistics for deconstruction and reuse. The overarching aim of these tools is to create reliable information pathways that connect design, construction, operation, and end of life stages, thereby reducing information asymmetries that have historically hindered circular practices.

Integration of digital platforms for circular decision-making is a key theme in the literature and remains an evolving frontier. Many early applications treat BIM, LCA tools, material databases, and procurement systems as separate modules, requiring manual data transfer and increasing the risk of inconsistencies. Recent work seeks to integrate these tools into cohesive platforms that can support multi-criteria decision-making across environmental, economic, and functional dimensions. For instance, BIM-LCA integration enables designers to assess the environmental impacts of design options directly within the modelling environment, using linked product databases and impact indicators (Baker, *et al*., 2019, Lysaght, *et al*., 2019). When combined with material passports and cost data, this integration allows practitioners to evaluate trade-offs between initial cost, embodied carbon, adaptability, and future reuse potential. Some platforms incorporate multi-criteria decision analysis techniques that can rank design alternatives based on project-specific priorities, such as minimising global warming potential, maximising reuse rates, or optimising life cycle costs.

Digital platforms also enable new forms of collaboration and governance. Web-based project dashboards can communicate circular performance indicators to clients, contractors, and regulators, increasing transparency and accountability. Marketplaces for reclaimed components and recycled materials can be linked to BIM and stock modelling tools, allowing designers to search for available secondary materials that match performance requirements and quantities. This integration helps bridge the gap between design intent and material supply, making circular options more tangible and practical (Darko, *et al*., 2019, Magrabi, *et al*., 2019). Furthermore, digital platforms can embed regulatory requirements, certification schemes, and client guidelines, providing automated checks for compliance with circular procurement criteria or building codes that encourage reuse and high recycled content.

Despite these advances, research highlights several challenges related to data quality, interoperability, governance, and skills. Many digital tools rely on detailed and standardised data that are not yet consistently available across products, regions, and projects. Proprietary software and closed data formats can limit interoperability and create vendor lock-in, which hampers the seamless exchange of information along the value chain. Data governance questions arise around who owns and controls the data embedded in BIM models, digital twins, and material passports, particularly over long timeframes that span multiple ownership cycles. Concerns about data privacy, cybersecurity, and liability must be addressed if stakeholders are to trust and rely on digital systems for critical decisions (Andriushchenko, *et al*., 2019, Duan, Edwards & Dwivedi, 2019).

There are also human and organisational dimensions that influence the effectiveness of digital enablers. Implementing BIM, digital twins, and advanced databases requires investment in training, process redesign, and cultural change within organisations that have long used paper-based or fragmented digital tools. Small and medium-sized enterprises may face particular barriers due to limited resources and skills. The benefits of digital enablers for circularity are not automatic. They depend on clear circular goals, supportive procurement practices, and leadership that prioritises long-term value over short-term cost minimisation (Briscoe, Sadedin & De Wilde, 2011, Kitchin, 2014).

Overall, digital and technological enablers offer powerful opportunities to support circular construction by making material flows visible, enabling precise environmental assessments, and facilitating new business models based on reuse and performance. Building Information Modelling, digital twins, and material passports provide foundational capabilities for documenting and tracking materials and components. Blockchain and related tools enhance trust and traceability in complex value networks. Integrated digital platforms bring these elements together into decision environments where environmental, economic, and functional considerations can be evaluated in a comprehensive way. As research and practice continue to evolve, the challenge is to move from isolated pilot applications towards scalable, interoperable, and inclusive digital ecosystems that embed circularity as a routine criterion in the planning, design, construction, and management of the built environment.

2.5. Barriers, Drivers, and Contextual Factors

Barriers, drivers, and contextual factors shape how circular economy principles are translated from abstract ideas into concrete practices within the construction industry. The literature consistently points to a complex interplay of regulatory, institutional, economic, cultural, and technical barriers that slow the uptake of circular strategies, while at the same time highlighting a range of policy incentives, market drivers, and stakeholder motivations that can accelerate change. These dynamics vary significantly across regions and project scales, with particularly sharp contrasts between developed and developing contexts where governance structures, market maturity, and resource constraints differ (Aksenova, *et al*., 2019, Xu, *et al*., 2019).

Regulatory and institutional barriers frequently arise from building codes, standards, and procurement rules that were designed for linear, conventional construction. Many regulations implicitly assume the use of new materials and traditional construction methods, leaving limited room for innovative practices such as component reuse, modular relocation, or performance-based service models. Liability concerns and strict compliance requirements can make actors wary of using reclaimed components or remanufactured products, especially when certification pathways are unclear. Institutional routines within public agencies and large companies often reinforce path dependency, favouring tried-and-tested specifications, contract forms, and risk allocation mechanisms that sit uneasily with long-term circular strategies (Asch, *et al*., 2018, Yellanki, 2016). Fragmented governance, where responsibilities are divided among multiple ministries, agencies, and local authorities, further complicates coordinated action on circular construction.

Economic barriers are equally prominent in the literature. Circular strategies such as design for disassembly, detailed material documentation, and deconstruction frequently involve higher upfront costs, longer planning phases, or more complex logistics than conventional approaches. The benefits of circular practices often accrue over extended time horizons or to parties other than those making the initial investment, creating misaligned incentives. For instance, developers who sell buildings shortly after completion may not be motivated to invest in features that enable future reuse or easy renovation. Market prices for virgin materials often fail to reflect environmental externalities, making secondary materials less competitive. Financing structures and valuation practices may not recognise the residual value of components or the risk reduction associated with adaptable, long-lived buildings (Blanco, *et al*., 2018, Demchenko, De Laat & Membrey, 2014).

Cultural and organisational factors also constrain circularity. The construction sector is characterised in many studies as conservative, with a strong reliance on established practices and a tendency to avoid perceived risks. Designers, contractors, and clients may have limited awareness of circular concepts or may associate reuse and recycled materials with lower quality. Time pressure, tight margins, and adversarial contract cultures can discourage experimentation and collaboration (Woodhead, Stephenson & Morrey, 2018). Skills gaps are reported across professions, from architects and engineers who may lack training in design for disassembly and life cycle thinking, to site workers and demolition contractors who may not be familiar with selective deconstruction techniques. These cultural and knowledge-related barriers interact with technical challenges related to the heterogeneity of existing building stocks, the difficulty of predicting future uses, and the lack of standardised interfaces that facilitate component interchangeability.

Against this backdrop, the literature identifies a range of policy incentives, market drivers, and stakeholder motivations that can counterbalance these obstacles. Policy instruments such as landfill taxes, material-specific recycling targets, extended producer responsibility schemes, and green public procurement requirements are particularly influential. When disposal becomes more expensive and public clients specify minimum levels of reused or recycled content, circular alternatives can become more attractive (Awe, Akpan & Adekoya, 2017, Osabuohien, 2017). Building regulations that explicitly allow or encourage reuse and modularity, combined with certification schemes for reclaimed components, can reduce perceived risks. Urban development strategies that frame cities as material banks and include circularity goals in planning policies also help create a supportive environment.

Market drivers include rising demand for low-carbon and resource-efficient buildings, driven by climate commitments, investor expectations, and corporate sustainability agendas. Certification systems such as green building rating tools can reward circular features, influencing value propositions and marketing strategies. Companies may see competitive advantage in offering circular services, such as take-back schemes, leasing of building elements, or integrated design–build–operate contracts that align long-term performance with revenue. The emergence of secondary material marketplaces and specialised deconstruction and remanufacturing firms provides new business opportunities and begins to normalise circular practices. In some contexts, scarcity of certain materials or volatile commodity prices push stakeholders to consider more resilient, circular supply chains (Akpan, Awe & Idowu, 2019, Ogundipe, *et al*., 2019).

Stakeholder motivations are diverse and often extend beyond immediate economic gains. Architects and engineers may be driven by professional ethics and innovation agendas, seeking to pioneer regenerative design and reduce environmental impacts. Municipalities may embrace circular construction to achieve waste reduction and climate targets while stimulating local employment in recycling and refurbishment industries. Developers and property owners may recognise reputational benefits and risk mitigation associated with future-proof, adaptable buildings that maintain value under changing regulations and market conditions. End-users and communities may support circular approaches that reduce disruption, improve indoor environmental quality, or preserve cultural heritage through adaptive reuse (Awe & Akpan, 2017).

Regional and project-scale differences strongly mediate how these barriers and drivers play out. In many developed economies, particularly in parts of Europe, relatively mature regulatory frameworks, strong policy signals on climate and waste, and growing experience with green building standards have created a fertile context for circular construction pilots and early mainstreaming. There, research documents advanced examples of design for disassembly, urban mining strategies, and digital platforms for material passports and secondary markets. Nevertheless, even in these contexts, fragmentation of responsibilities, conservative industry cultures, and limited scalability beyond flagship projects remain significant issues (Akpan, *et al*., 2017, Oni, *et al*., 2018).

In developing and emerging economies, the picture is more heterogeneous. On one hand, rapid urbanisation and infrastructure expansion create enormous material flows and opportunities to embed circular principles from the outset of new developments. Informal reuse and repair practices are often widespread, with high rates of material recovery driven by necessity and local entrepreneurship. On the other hand, weak regulatory enforcement, limited access to finance, and a focus on addressing urgent housing and infrastructure deficits can push circular concerns down the priority list. Formal construction sectors may lack the institutional capacity and technical infrastructure to support sophisticated circular strategies such as BIM-integrated material passports or certified remanufacturing (Akomea-Agyin & Asante, 2019, Awe, 2017, Osabuohien, 2019). In such contexts, research emphasises the importance of adapting circular economy concepts to local realities, building on existing informal practices and focusing on achievable interventions such as improved sorting of construction waste, basic deconstruction training, and incremental strengthening of regulations and incentives.

At the project scale, the literature shows that context-specific factors such as project size, client profile, and procurement route strongly influence circular outcomes. Large public or institutional clients with long-term asset management responsibilities are often better positioned to adopt circular strategies, because they can internalise life cycle benefits and influence supply chains through procurement requirements. Design–build and integrated project delivery models can create more collaborative environments for circular innovation than traditional design–bid–build contracts (Awe, Akpan & Adekoya, 2017, Osabuohien, 2017). Conversely, speculative developments, small projects with limited budgets, and highly fragmented subcontracting arrangements tend to reinforce short-term, linear choices. Local availability of secondary materials, presence of deconstruction and recycling facilities, and regional cultural attitudes toward reuse further modulate what is feasible and attractive.

Overall, research on barriers, drivers, and contextual factors underscores that the transition to circular construction is not just a technical challenge but a socio-institutional transformation. Regulatory rigidity, institutional inertia, misaligned economic incentives, cultural conservatism, and technical complexity collectively hold back circular progress. Yet, targeted policy instruments, evolving market expectations, and motivated stakeholders can and do create pockets of circular practice that demonstrate feasibility and value. Understanding the specific constellations of barriers and drivers in different regions and project types is crucial for designing interventions that are both ambitious and realistic. This contextual sensitivity is central to moving from isolated exemplary projects towards systemic, sector-wide adoption of circular economy principles in the construction industry (Akpan, Awe & Idowu, 2019, Ogundipe, *et al*., 2019).

2.6. Research Gaps and Future Directions

Research on the circular economy in the construction industry has expanded significantly in recent years, yet important gaps remain that limit its ability to guide a large scale transition from linear to circular practices. One set of underexplored themes concerns circular business models, social equity implications, and financial mechanisms that can sustain circular strategies over time. Much of the literature still focuses on technical solutions such as design for disassembly, material selection, and recycling processes, while giving comparatively less attention to how firms actually organise their activities, generate revenue, and distribute risks and benefits in circular projects. Product service systems, leasing arrangements for building components, performance based contracts, and producer take back schemes are often mentioned as promising models, but empirical studies that analyse how these models perform in practice, under what conditions they succeed, and how they can be scaled across different market segments are still limited (Awe & Akpan, 2017). Similarly, there is a need for deeper investigation of value chain governance, including questions of ownership, responsibility, and power relations among developers, contractors, suppliers, and end users in circular construction.

Social equity and justice considerations are another important yet relatively neglected theme. While circular construction is often promoted for its environmental benefits, the distributional consequences of circular strategies receive less attention. There is limited research on how jobs, health impacts, and economic opportunities linked to deconstruction, remanufacturing, and secondary material markets are distributed among different social groups, regions, and communities. Questions about labour conditions in recycling and refurbishment industries, potential gentrification linked to high profile adaptive reuse projects, and access to affordable, circular housing are only beginning to be explored. Integrating social life cycle assessment, participatory methods, and justice centred frameworks into circular construction research would help ensure that the transition to circularity does not reproduce or deepen existing inequalities (Akpan, *et al*., 2017, Oni, *et al*., 2018).

The financial dimension of circular construction also remains insufficiently examined. Many studies note higher upfront costs and uncertain payback periods for circular strategies, but few provide detailed financial models that incorporate life cycle costs, revenue from secondary materials, risk reduction benefits, and potential policy incentives. There is a need for research that engages with investors, lenders, and insurers to understand how circular projects are assessed, what kinds of collateral and guarantees are required, and how financial instruments such as green bonds or impact investment funds could be tailored to support circular construction. Without robust financial evidence and suitable funding mechanisms, even technically sound circular solutions may struggle to move beyond pilot projects (Akomea-Agyin & Asante, 2019, Awe, 2017, Osabuohien, 2019).

Across these thematic gaps, there is a broader need for standardized metrics, high quality data, and cross disciplinary collaboration. Existing studies use a wide variety of indicators to evaluate circularity, including recycling rates, embodied carbon, waste diversion, and qualitative assessments of adaptability, which makes comparison across projects and regions difficult. Developing common frameworks for measuring circular performance at product, building, and stock levels, and aligning them with emerging international standards, would help create a more coherent evidence base. Such metrics should capture not only environmental outcomes but also economic and social dimensions, including employment, affordability, and resilience (Akpan, *et al*., 2017, Oni, *et al*., 2018). High quality data are essential for populating these metrics, yet many regions lack reliable statistics on construction and demolition waste, material flows, and building stock characteristics. Research that focuses on data collection methods, open databases, and protocols for sharing information among stakeholders is therefore a priority.

Cross disciplinary collaboration is vital because circular construction sits at the intersection of engineering, architecture, urban planning, economics, law, and social sciences. However, many studies remain confined within disciplinary silos, which can lead to partial or fragmented analyses. Future research directions include more integrated projects that bring together technical modelling with institutional analysis, legal studies on ownership and liability, and behavioural research on stakeholders and users. Collaborative platforms that connect academia with industry, government, and civil society can support co creation of knowledge, ensure that research questions reflect practical challenges, and facilitate the testing of solutions in real projects.

Looking ahead, several priority areas for policy, practice, and education emerge from these gaps. On the policy side, there is a need for coherent regulatory frameworks that align waste, building, and planning regulations with circular objectives, while providing clear guidance on the safe and effective use of reclaimed and recycled materials. Policies that internalise environmental externalities, such as carbon pricing and increased landfill charges, can shift economic signals in favour of circular options, but they should be designed in ways that protect vulnerable groups and support small and medium sized enterprises. Public procurement is a powerful lever for change; future research can support the development of criteria, benchmarks, and model contracts that embed circular requirements without creating undue administrative burdens (Akomea-Agyin & Asante, 2019, Awe, 2017, Osabuohien, 2019).

In practice, the construction industry requires tools and processes that translate circular principles into everyday decision making. This includes design guidelines that integrate circularity from the earliest stages, procurement templates that facilitate long term partnerships and take back arrangements, and operational protocols for selective deconstruction and material quality control. Future work should document and evaluate real projects that employ these tools, capturing lessons learned and transferable practices across different building types and contexts. Special attention is needed for renovation and retrofit projects, which constitute a large share of construction activity and offer significant opportunities for circular interventions in existing stocks (Leising, Quist & Bocken, 2018, Pomponi & Moncaster, 2017).

Education and professional development represent another crucial frontier. Many current practitioners were trained within linear paradigms and may lack familiarity with circular design concepts, life cycle assessment, and new digital tools. Integrating circular economy content into architecture, engineering, and construction management curricula, as well as providing continuing education for professionals, will be important for building capacity. Research can help identify effective pedagogical approaches, including project based learning, interdisciplinary studios, and partnerships with real world projects that expose students to the complexities of implementing circular strategies (Ghisellini, Ripa & Ulgiati, 2018, Heshmati, 2017).

In sum, future directions for circular economy research in the construction industry lie in deepening and broadening the agenda beyond technical solutions to encompass business models, social justice, finance, governance, and education. Standardised metrics, robust data, and cross disciplinary collaboration will be key enablers, while policy, practice, and education must evolve in parallel to create an ecosystem that supports systemic change. By addressing these gaps, the research community can provide more comprehensive and actionable guidance for stakeholders seeking to transform the construction sector into a truly circular and inclusive part of the wider economy.

2.7. Conclusion

The body of research on the circular economy in the construction industry portrays a field that is both dynamic and uneven. Across the literature, there is growing consensus that circular principles can substantially reduce resource consumption, waste generation, and greenhouse gas emissions by acting at every stage of the construction life cycle. Conceptual work has clarified that circular construction is not limited to recycling but involves a hierarchy of R strategies that prioritise refusing, reducing, reusing, repairing, refurbishing, and remanufacturing before energy recovery. These studies contrast linear and circular models of the built environment and employ frameworks such as industrial ecology, life cycle thinking, systems approaches, and urban metabolism to show how materials, components, and buildings can be treated as long lived assets and material banks rather than disposable products. Methodological developments, including systematic reviews, case studies, quantitative models, and survey based social research, have started to reveal how different circular strategies perform in practice and which combinations are most promising, although fragmentation of indicators and system boundaries still limits comparability across studies.

Empirical work on design and life cycle strategies demonstrates that design for adaptability, disassembly, and reuse is central to enabling future circular outcomes. Material selection, prefabrication, and modular construction are repeatedly shown to support reduced waste, improved resource efficiency, and higher recovery rates, provided that they are combined with reversible connections, standardised interfaces, and clear documentation. At the end of life, research on deconstruction, remanufacturing, and high quality recycling confirms both the technical feasibility and the economic and organisational challenges of shifting away from conventional demolition. Secondary material markets and digital marketplaces are beginning to bridge supply and demand for reclaimed components, but they remain fragile in many regions. Digital and technological enablers, including Building Information Modelling, digital twins, material passports, and traceability tools such as blockchain, are transforming the information landscape by making material stocks and flows more visible and by supporting scenario based decision making. Integrated digital platforms that couple design models with environmental assessment, cost data, and material databases suggest a path towards routine circular performance evaluation, though issues of data quality, interoperability, and governance remain unresolved.

The literature also makes clear that technical potential alone will not deliver circular construction. Regulatory frameworks, institutional routines, economic incentives, cultural norms, and technical constraints form a web of barriers that slow adoption. Regulations that implicitly privilege new materials, fragmented governance, short investment horizons, and conservative industry cultures all contribute to a default preference for linear, established solutions. At the same time, important drivers are emerging. Policy instruments that increase the cost of landfill disposal, set recycling targets, or embed circular criteria in public procurement are shifting the economic calculus. Market demand for low carbon buildings, corporate sustainability commitments, and reputational benefits for innovators are encouraging firms to experiment with circular designs and business models. Regional and project scale differences are significant: some European and high income contexts show advanced pilots and policy frameworks, while many developing regions combine strong informal reuse with weaker formal institutions and limited digital infrastructure. These differences underline the need for context sensitive strategies rather than one-size-fits-all prescriptions.

For researchers, the implications of this body of work are several. There is a clear need to deepen investigation into underexplored themes such as circular business models, financial mechanisms, social equity implications, and governance arrangements that can support long term stewardship of built assets. Methodological priorities include the development of standardised, multi dimensional metrics for circular performance, improved data on material flows and building stocks, and more integrated projects that combine technical modelling with institutional and socio cultural analysis. Engaging directly with practitioners and public authorities through living labs, action research, and co creation projects can help ensure that research questions and methods remain grounded in real constraints and opportunities.

For practitioners, the literature points to the importance of embedding circular thinking in everyday decisions, starting from the earliest design stages. Architects, engineers, contractors, and clients can use existing tools and guidelines to design for adaptability and disassembly, choose materials and systems that retain value over time, and plan for selective deconstruction and high quality recovery. Investing in digital competencies and collaborative processes around BIM and related technologies can provide the information backbone required for circular strategies. At the organisational level, rethinking business models to include service offerings, take back schemes, and long term performance based contracts can align commercial interests with circular outcomes. Collaboration across the value chain, including partnerships with deconstruction firms, remanufacturers, and secondary material marketplaces, is essential to turn design intent into realised circular flows.

For policymakers, findings from the review emphasise the need for coherent, predictable policy frameworks that both remove regulatory obstacles and create positive incentives for circular construction. This involves updating building codes and standards to explicitly accommodate reuse and remanufactured components, aligning waste and planning regulations with circular goals, and leveraging public procurement to signal demand for circular solutions. Fiscal instruments, such as landfill taxes, tax incentives for refurbishments and deconstruction, and support for digital infrastructure and skills development, can help shift economic conditions. Equally important is attention to social outcomes, including job quality in recycling and deconstruction industries, access to affordable circular housing, and inclusive participation of smaller firms and communities in new circular value chains.

In reflecting on how to accelerate the transition to circular construction systems, the reviewed literature suggests that progress depends on coordinated action across multiple domains. Technical innovations in design, materials, and digital tools must be matched by institutional reforms, financial innovation, and cultural change within the industry. Exemplary projects, while valuable, need to be accompanied by mechanisms that capture lessons learned and translate them into standards, regulations, and educational curricula. Universities and professional bodies have a key role in equipping current and future practitioners with circular economy knowledge and skills and in fostering interdisciplinary collaboration. Ultimately, the transition to circular construction is best understood as a long term, iterative process in which policies, markets, and practices evolve together. By recognising the interdependence of these elements and by addressing identified research gaps in a coordinated way, the construction sector can move closer to a built environment that conserves resources, reduces emissions, and supports more just and resilient societies.

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