CIRCULAR ECONOMY STRATEGIES FOR SUSTAINABLE RESOURCE MANAGEMENT IN THE CONSTRUCTION INDUSTRY

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Abstract
The construction industry is one of the largest consumers of natural resources, generating significant waste and contributing to environmental degradation. Circular economy (CE) strategies offer a transformative approach to sustainable resource management by closing material loops, reducing waste, and enhancing resource efficiency. This study examines the implementation of CE principles in the construction sector, focusing on design and construction aspects, material reuse, recycling, and innovative business models. By adopting strategies such as modular construction, cradle-to-cradle design, and the use of secondary raw materials, the industry can achieve significant reductions in environmental impact. The integration of digital tools, such as Building Information Modelling (BIM), enables more effective lifecycle management and resource tracking. Several challenges are discussed, such as consumer protection in the construction industry, product lifecycle extension through reducing, reusing, and repairing, as well as socio-economic impacts of circular economy practices on consumer rights and possibilities for overcoming barriers to circular economy implementation. The findings underscore the critical role of policy frameworks, technological advancements, and cross-sectoral partnerships in driving systemic change.

Key words: *Circular Economy, Construction Industry, Consumer Protection, Barrier to CE implementation.*

Introduction

The conventional construction industry (CI) has a linear and unsustainable approach, based on the “take, make, dispose” model (zu Castell-Rüdenhausen et al., 2021). The result is the CI being the among the world’s largest consumer of natural resources as well as waste producer. Therefore, a paradigm shift in the construction is required which will transform the linear economy model to a circular model.

The Ellen MacArthur Foundation defines the CE principle as “an industrial system that is restorative or regenerative by intention and design” and then extended as “a new way to design, make, and use things within planetary boundaries” (*Circular Economy Introduction - Overview*, 2021). Circular economy (CE) strategies offer a transformative approach to sustainable resource management by closing material loops, reducing waste, and enhancing resource efficiency. To decrease resource consumption, the CE is based on a systematic approach which integrates the supply chain of materials and enables waste elimination by closing the materials flow. Also, CE can be aligned with industrial ecology (Deutz et al., 2017), considering it is based on sharing of resources between different sectors through industrial symbiosis and preserving the value of materials to be reused.

Even though there have been certain efforts in the CI to implement CE strategies, many unresolved issues persist, among which quantification of resources flow, assessing the ecological consequences, develop indicators and criteria for assessment, as well as identification of strategies (Petit-Boix & Leipold, 2018). The CE challenges in the construction industry are multi-dimensional, and the areas of major challenges are pinpointed as: design & construction strategies, supply chain management, policy strategies for CE adoption, End-of-Life (EoL) principles, CDW management strategies, information exchanges & analytics for CE (Antwi-Afari et al., 2021). Also, in the business sector, at the company level, there are no common CE practices in terms of evaluation of circularity performances (Sassanelli et al., 2019)

This paper aims to make an overview of the implementation of CE principles in the construction sector, focusing on design and construction aspects, material reuse, recycling, and innovative business models. Also, the integration of digital tools in the construction industry is investigated, with a focus on Building Information Modelling (BIM), which enable implementation of CE principles as well as more effective lifecycle management and resource tracking.

Further, several challenges are discussed, such as consumer protection in the construction industry, product lifecycle extension through reducing, reusing, and repairing, as well as socio-economic impacts of circular economy practices on consumer rights and possibilities for overcoming barriers to circular economy implementation.

The findings underscore the critical role of policy frameworks, technological advancements, and cross-sectoral partnerships in driving systemic change.

In the following sections the methodology of this research is laid out followed by analysis of Circular Economy Design and Construction aspects, Digital tools development and implementation in CE

Methodology

The research methodology used in this paper is consisted of eight steps, such as (Xiao & Watson, 2019): (1) formulating the research problem; (2) developing and validating the review protocol; (3) conducting a literature search; (4) screening for inclusion based on publication language and date range; (5) assessing the quality of selected studies; (6) extracting relevant data; (7) analyzing and synthesizing the data; and (8) reporting the findings.

Scoping review is used to analyze the existing literature and to provide broad overview of the research topic. A scoping literature review aims to provide a comprehensive overview of studies across various quality levels (Xiao & Watson, 2019). The target papers, the Web of Science and Scopus databases were used with theme-based specific and relevant keywords in this research area being made referenced to, e.g. ‘circular economy’, ‘construction industry’, ‘consumer protection’, ‘resource management’. The study findings are organized and presented in subsequent sections further in this paper.

Circular Economy Design and Construction aspects

The construction sector is regarded as having significant potential to transition towards a Circular Economy (CE) model by embracing sustainable products and technologies (Smol et al., 2015). By enhancing the use of waste materials throughout various phases of the building life cycle, it can lead to a decrease in material expenses and overall construction costs, while also minimizing embodied energy and other environmental effects associated with the overconsumption of construction resources (Akanbi et al., 2019).

The recent focus on CE and its potential integration into the construction industry has prompted a reevaluation of supply chains to better facilitate waste reduction and reuse, as effectively recovering construction materials for recycling or direct reuse is crucial for a successful transition to CE (Akinade & Oyedele, 2019; Pan et al., 2015). These initiatives have potential to reduce the demand for new raw materials and decrease the volume of waste sent to landfills.

Although producing construction materials typically requires substantial raw materials and energy, a large portion of these resources ends up being downcycled or wasted after use. Regrettably, the industry currently captures only a small fraction of the economic value and durability of these materials under existing practices. Adopting CE principles effectively can address these challenges by promoting material recirculation, such as through designing for disassembly with mechanical joints, thereby extending the lifespan of construction components for reuse in future projects or different applications (Schiller et al., 2019).

Initially, the CE concept was shaped around the 3R's principles, Reduce, Reuse, and, Recycle. The 3R's principles were later extended with intention to stimulate the transition towards CE, organized in three strategies (Rahla et al., 2021).

The first strategy consists of three actions:

1. *Refuse*: Depreciate a product with dire impacts and proposing a different one with identical or better functions and fewer impacts;
2. *Rethink*: Intensify the product use and adopt smarter strategies as sharing economy or products with multiple functions; and,
3. *Reduce*: Decrease virgin materials and energy consumption while enhancing efficiency.

The Second strategy considers product lifespan extension and consists of:

4. *Reuse*: Reuse a discarded product that keeps the same functions by another user;
5. *Repair*: Fix a damaged product to give back its initial performance;
6. *Refurbish*: Renovate an outdated product to make it as a new one;
7. *Recycle*: Include, into the manufacturing process of a product, materials that reached their end-of-life use to make materials with same, higher (upcycle), or lower (downcycle) qualities; and,
8. *Recover*: A process of retrieving heat, electricity, or fuel from non-recyclable materials by incineration.

The third strategy is comprised of the actions:

9. *Remanufacture*: Make a product using parts from a damaged product that had the same functions; and,
10. *Repurpose:* Make a product using parts from a damaged product that had different functions.

The Ellen MacArthur Foundation outlined three principles to embrace CE (*Circular Economy Introduction - Overview*, 2021):

1. "to preserve and enhance natural capital by controlling finite stocks and balancing renewable resource flows."
2. "to optimize resource yields by circulating products, components, and materials at the highest utility at all times in both technical and biological cycles."
3. "to foster system effectiveness by revealing and designing out negative externalities."

Researchers aggregate the broader effects of implementing Circular Economy (CE) principles in the construction sector, such as (Hossain et al., 2020):

(i) enhancing the use of sustainable materials by fostering collaboration among various stakeholders;
(ii) increasing material efficiency through the recycling and reuse of construction resources; and
(iii) preventing unnecessary waste generation and landfill disposal.

To facilitate the transition to circular construction, researchers propose several strategies, such as (Stephan & Athanassiadis, 2018):
(i) utilizing sustainable and durable materials,
(ii) adopting the design for disassembly approach,
(iii) incorporating modular and prefabricated components, and
(iv) creating recovery systems, akin to take-back programs in the manufacturing sector.

Other researchers present three tools to expedite CE adoption within the construction industry in Scandinavian countries (Høibye & Sand, 2018):
(i) defining requirements and documentation standards for the quality of building materials, including sharing information on technical performance and recycling rates, and enhancing traceability;
(ii) creating guidelines for reused building products and those made from recycled materials, which involves establishing minimum standards and green resource efficiency criteria, as well as facilitating the exchange of reused products; and (iii) setting requirements for waste and demolition plans, encompassing the screening, mapping, and sorting of valuable building items for reuse, establishing recycling targets and end-of-waste criteria, along with providing guidelines and training for demolition firms.

Authors (Minunno et al., 2018) propose seven strategies for circular prefabricated building construction, such as:
(i) reduction of waste based on lean production chain.
(ii) utilization of by-products in the production of new materials or components.
(iii) reuse of replacement parts and components
(iv) encourage design of adaptability (for another cycle with different applications).
(v) design for disassembly using BIM (to improve the end-of-life deconstruction),
(vi) design with attention for ensuring recyclability of reused materials is in the sixth strategy.
(vii) use of tracking system for gathering information, tracking locations and life cycle to facilitate the materials or components being put to another cycle after dissemble or deconstruction.

Multitude of design and construction strategies are examined regarding their level of application and readiness to be utilized by the industry (Eberhardt et al., 2022), such as: assembly/disassembly, material selection/substitution, adaptability/flexibility, modularity, prefabrication, secondary materials, durability, standardisation, component and material optimisation, reusing, existing building/components/materials, optimised shapes/dimensions, accessibility, layer independence, material storage, short use, symbiosis/sharing. The most frequent strategy in the literature is assembly/disassembly, followed by material selection/substitution and adaptability and flexibility (Eberhardt et al., 2022).

Three priority barriers of CE in the design stage are identified, such as (Mahpour, 2018): agency and ownership issues of end-of-life of materials; lack of integration of sustainable waste management and potential reuse and associated uncertainty in C&D waste manage ment. Also, other design challenges are durability of materials, lack of incentives of recycled materials or components, uncertainty of material flows, lack of material banks, material passports etc.

One of the most crucial parameters in DfD is the choice of the construction technology and how building elements will be assembled and disassembled. Researchers (Crowther, 2005) outlined a total of 27 principles for Design for Disassembly (DfD) that can be categorized as reducing the amount of input and reliance on safe and healthy secondary materials, standardizing the connection between materials and components while considering disassembly at the end-of-life, and retaining information regarding all materials and components involved in a building.

Authors (Eberhardt et al., 2022) suggest that in order to convey a comprehensive and uniform adoption of CE in the building industry a new design typology is required which will facilitate CE-oriented decision-making in a building context and which will prioritise design and construction strategies according to their potential for minimising building-related environmental impacts.

The ‘design for disassembly’ principles are noted to have a potential to reduce the buildings embodied greenhouse gas emissions by 36% in case the concrete elements are reused. In other case study were a building is ‘upcycled’, it is shown it can have 46% lower embodied greenhouse gas emission compared to the ‘design for disassembly’ building when building components and materials were reused and recycled (Rasmussen et al., 2019). Nevertheless the environmental implications of CE strategies need to be further investigated (Eberhardt et al., 2022).

Digital tools and Circular Economy

The rapid advancement of digital tools and technologies enables an increased uptake of CE in the construction industry. Information and Communication Technologies (ICT) are recognized as a critical part of the path towards CE (Singh et al., 2021) and ICT-based solutions are prioritised for future CE implementation (Demestichas & Daskalakis, 2020).

The digital technologies can be utilized in various domains, such as: communication technologies (communication infrastructure, wireless transmission etc.); computing technologies (ex. cloud computing); cyber-physical systems (additive manufacturing (3D printing); Greens Sensing Virtual Enterprise, digital twins); data analysis and artificial intelligence algorithms (big data analytics, case-based reasoning, data and model integration, data visualization, dynamic game theory, dynamic programming, evaluation models, fuzzy logic, heuristic algorithms, machine learning, recommender systems, semantic processing, and others); Data Collection and Internet of Things (IoT) (asset tagging, building information modeling (BIM), satellite imaging, GIS, SCADA, and others); data management and storage; software and simulation technologies (digital platforms, PLM systems, simulation technologies, smartphone applications, software tools); smart grids and products.

Regarding data collection and IoT it is noted that among the most widely used technologies are smart tags and radio-frequency identification (RFID) (Demestichas & Daskalakis, 2020). The smart tags are small devices which combine memory, data processing and communication services. Smart tags enable unique identification of items and tracking of the environmental conditions in which a product is maintained. This technology enables improved handling of resources and facilitates decision-making (Gligoric et al., 2019). The RFID tags, have a small microchip and enable identification of objects, using electromagnetic fields (Tuyls & Batina, 2006). Further, IoT is a global network of interconnected objects which have unique addresses and can communicate using standard protocols (Gubbi et al., 2013) and can have a range of implementation in resource management.

Building Information Modelling (BIM) enables creation of an accurate virtual model of a building and simulating all building life-cycle stages. The BIM model does not only represent the building in three dimensions (3D), but adds the dimension of time (4D), costs (5d) etc., providing opportunities for multitude dimensions. The BIM model integrates all building systems and technologies and enables identification of potential design, construction, or operational issues. In this regard, RFID and BIM technologies provide the building elements to be more traceable, adaptable, and reusable in new designs. BIM provide analysis of the disassembly and deconstruction of a building, ensuring efficient materials recovery as well as for checking if building designs are compliant with the concepts of CE (Akanbi et al., 2019).

However, it is noted that there is an insufficient uptake of ICT technologies for CE in construction industry. Authors investigate several challenges in adopting circular ICT solutions, such as (Demestichas & Daskalakis, 2020): consumer attitude, corporate responsibility, cooperation and trust, data uncertainty, economic, environmental impact, information use, lack of capacity, policies, product design and security.

Data uncertainty is identified as another obstacle for the CE. Van Schalkwyk et al. underline that some simulation models are imperfect and need to be enriched with further data (van Schalkwyk et al., 2018). Also, "Noise" in lifecycle big data is noted with a possible negative impact on the accuracy and reliability of decisions (Zhang et al., 2017).

Also, the lack of government laws and regulations is also noted as a barrier in the CE uptake (Rizos et al., 2016). Authors (Watkins et al., 2013) note that current legislation does not adequately support the development of potential symbiotic products that make use of multiple residue streams of industrial processes.

CE Business models in the construction industry

A Business Model (BM) is a sustainable method of conducting a business (Nielsen & Lund, 2014). The successful implementation of the principles of CE, in large part depends on the business models which will be used. As the construction business environment is becoming more competitive, the Circular Economy Business Model (CEBM) are receiving considerable attention. As previously discussed, the implementation of CE in the construction industry imposes reforms in all value chains in the industry.

The distinctions in supply chains between traditional BMs and CEBM arise from the essential processes of closing, slowing, and streamlining material and energy flows (Bocken et al., 2016).

Value in a conventional BM is frequently focused on the financial benefit to investors and clients. In a CEBM, value is viewed more broadly, considering the environment, society, and a more comprehensive range of value chain partners (Huovila & Westerholm, 2022). Even more, the CEBM model needs to be integrated all phases of the building life-cycle, at every stage, from planning and design through construction.

Shafer et al. (Shafer et al., 2005) examined twelve criteria and found forty-two elements categorised as strategic decisions, value networks, and creating and capturing value. Others developed a framework that includes a customer interface, core strategy, strategic resources, and value network (Hamel, 2001).

Researchers propose categorization of existing CEBM in nine categories: product life extension, product as a service, waste as a resource, circular supplies, resource recovery, resell, remanufacture, sharing platforms, and repair (Guerra et al., 2021). Others (Mackenbach et al., 2020) identified four CEBMs, refurbishment and reuse, repair and maintenance, product as a service, and upcycling, considering their adaptability, applicability, and usability in modular construction. However, there is a scarce research on CEBM in the construction industry and none of these studies have properly defined or elaborated on the practical applicability of the model (Jayakodi et al., 2024). Therefore, researchers define CEBM from the perspective of a construction organisation (Jayakodi et al., 2024). The organisational aspects are required to ensure the integration of CE in all supply chain processes in the construction.

Also, there is a need to reconsider ownership by introducing new ideas like product leasing or product-as-a-service (Cimen, 2021; Hartwell et al., 2021) as well as to support supply-chain models which encourage stakeholder collaboration and value co-creation (Hossain et al., 2020).

Six elements are identified for CEBM in CI (Jayakodi et al., 2024): value creation, value delivery, value proposition, value capture, the collaboration of stakeholders, and the lifecycle perspective, Figure 1.

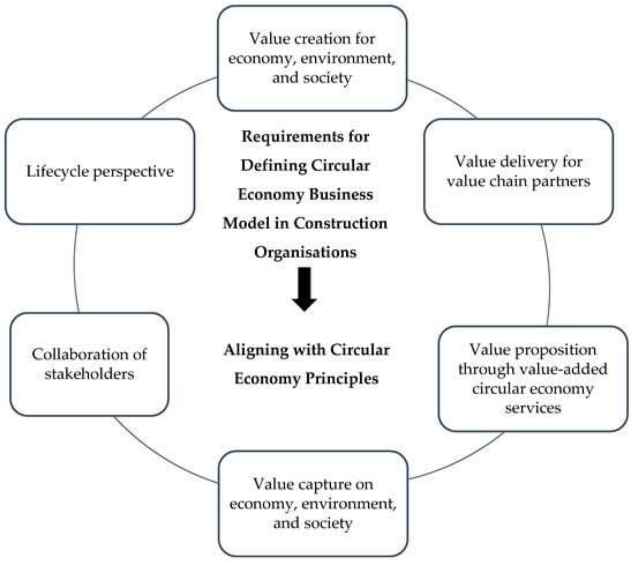

Figure 1. Requirements for defining circular economy business model in construction organisations (Jayakodi et al., 2024)

Consumer protection in the construction industry

In this section, several challenges are discussed, such as consumer protection in the construction industry, product lifecycle extension through reducing, reusing, and repairing, as well as socio-economic impacts of circular economy practices on consumer rights and possibilities for overcoming barriers to CE implementation. In the paradigm shift of sustainability and CE, the consumption behaviour is also changing. The alternative and collaborative ways of consumption, such as sharing, gifting, renting, bartering, swapping, lending, and borrowing are intensifying the use of idle assets, decrease the need for new product purchases, and promote possession reuse (Böcker & Meelen, 2017). Studies show that policy and governance, permits and specifications, technological limitation, quality and performance, knowledge and information, and, finally, the costs associated with the implementation of CE model at the early stage are the main barriers (Purchase et al., 2022), and they note an urgent need to introduce a global framework and a practicable pathway to allow companies to implement such models, regardless of their scale and location.

A considerable number of studies have explored consumer acceptance of remanufactured, refurbished, recycled, reused, or shared products as contributing to past circular strategies relating to slowing or closing the loop (Shevchenko et al., 2023).

The consumer activity that contributes to slowing or closing the material loop can be defined as a CE-oriented consumer activity, and researchers illustrate the tri-dimensional role of consumer activity in the CE model, Fig. 1. (Shevchenko et al., 2023).

Figure 1. Tri-dimensional role of the consumer in the CE (Shevchenko et al., 2023)

Consumer protection as the practice of safeguarding buyers of goods and services, and the public, against unfair practices in the marketplace also needs to deal with the new ongoing tide of CE transformation. While the CE practices hold the potential to significantly reduce the environmental footprint in construction industry, they also raise concerns related to consumer protection (CP). The consumer protection aims to protect consumers against defective goods, unsatisfactory services, unfair trade practices etc.

The CP in the construction industry should be aimed to provide consumers, i.e. property buyers, tenants, and investors, product quality and safety. Recycled and reused materials must meet stringent safety standards to guarantee that buildings constructed with these materials are structurally sound and free from health hazards. For instance, reclaimed wood, recycled concrete, or repurposed steel must be thoroughly inspected for contaminants or defects that could compromise building integrity or occupant safety. Regulators and industry stakeholders must establish robust certification systems and transparent documentation practices to assure consumers of the quality of materials and construction methods employed.

Transparency is another cornerstone of consumer protection in the circular economy. Buyers and tenants need access to detailed information about the materials and methods used in construction projects. Material passports—digital documents that provide comprehensive data about the origin, composition, and lifecycle of building materials—can play a crucial role in achieving this transparency. These passports empower consumers to make informed decisions and hold construction companies accountable for their environmental claims.

Economic considerations also intersect with consumer protection. The adoption of circular practices may lead to cost variations, with some materials or methods initially being more expensive due to limited supply chains or technological constraints. It is vital that consumers are not unfairly burdened with these costs. Policymakers can address this issue by offering subsidies or incentives for sustainable construction practices, thereby balancing affordability with environmental responsibility.

Lastly, legal frameworks must evolve to support consumer protection in the circular economy. Clear guidelines on warranties and liabilities are essential to address potential disputes over the durability and performance of recycled materials. Moreover, regulatory bodies should enforce strict penalties for greenwashing—the practice of misleading consumers about the environmental benefits of a product or service—to uphold ethical standards in the industry.

Conclusions

This research provides a comprehensive overview of the implementation of Circular Economy (CE) principles in the construction sector, with a particular focus on design and construction practices, material reuse, recycling, and innovative business models. Additionally, it investigates the integration of digital tools within the industry, emphasizing the role of Building Information Modelling (BIM) in enabling CE principles and enhancing lifecycle management and resource tracking. The study highlights several key challenges, including consumer protection in the construction sector, strategies for extending product lifecycles through reducing, reusing, and repairing, and the socio-economic implications of CE practices on consumer rights. It also explores pathways to overcome barriers to CE implementation.

The findings of the research underscore the pivotal role of policy frameworks, technological advancements, and cross-sectoral collaborations in fostering systemic change. By adopting strategies such as Design for Disassembly (DfD), adaptability, and materials upscaling, the construction industry can achieve significant reductions in environmental impact. Furthermore, the study emphasizes the need to address specific challenges, such as ensuring consumer protection, extending the lifecycle of construction products, and mitigating socio-economic impacts through equitable and sustainable CE practices.

To successfully adopt CE business models, it is crucial to identify key stakeholders, resources, activities, and services where CE can be effectively implemented. These models should be supported by a circular cost structure and benefit from the integration of digital technologies to facilitate new circular design and construction approaches. The literature reviewed in this study demonstrates that strategies such as adaptability, prefabrication, the use of sustainable and durable materials, and DfD principles are effective in achieving circular buildings. Future research should focus on evaluating the implications of various CE design and construction strategies in terms of consumer satisfaction, acceptance, and protection.

In conclusion, integrating CE principles into the construction industry also requires prioritizing consumer protection as a prerequisite for the widespread adoption of CE practices. Critical aspects such as safety, transparency, affordability, and robust legal frameworks must be emphasized. These measures will not only strengthen consumer confidence but also propel the construction industry towards a more sustainable and resilient future.

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