DESIGN FOR CIRCULARITY (DfC) IN CONSTRUCTION: A MINI-SCOPING REVIEW OF THE STRATEGIES

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ABSTRACT

Design for Circularity (DfC) is an approach that seeks to optimize materials and resources in construction projects to minimize waste generation and thereby extend the lifecycle of materials used. Conventionally, the Construction Industry (CI) is known for employing linear economy practices which consumes a vast amount of virgin resources, consumption of large amount of energy and generation of high quantities of waste. It has therefore become necessary that circular design be employed to enable a smooth transition to a circular economy (CE) for positive resource use and efficiency. Hence, a mini-scoping review aimed to investigate the key DfC strategies linked to the Circular Economy (CE) concept used in the construction industry and employed by design professionals. The methodology adopted the five-step process by Arksey and O'Malley and used PRISMA for data organization which led to the generation of the final list of articles used in the mini-scoping review. The mini-scoping review identified several key strategies that are employed to design for circularity in the construction and were discussed with relevant studies provided. The study, therefore, gives insight into DfC as an increasingly important concept that can reduce the construction industry's ecological footprint, thereby requiring further development and research to maximize its effectiveness. Thus, it is further suggested that future research emphasizes the identification of new DfC strategies, the development of existing ones and the integration of existing strategies in the construction industry processes. Again, there is a need for further collaboration between design professionals and other CI stakeholders to see to it that these strategies are prioritized to reduce waste and optimize materials resource usage.

Keywords: Design for Circularity (DfC), design strategies, construction industry (CI)

1.0 Introduction

The construction sector provides the infrastructure, buildings, jobs, and economic prosperity that people require. This has led to a rapid increase in the demands placed on the environment and infrastructure by the people as the new metropolis grows. As a result, the World Population Review detects that the world population will exceed 8 billion after 2025 (World Population Review, 2021). However, the construction industry is having negative environmental effects as a result of rapid urbanization.

More than 70% of today's economy relies on nonrenewable natural resources, the majority of which are used in the building and construction industry (OECD, 2015). The European Commission (2020) and Galvez-Martos and Istrate (2020) indicate that the construction sector is one of the five priorities that the

Circular Economy Action Plan for the European Union targets due to it accounting for 35% of all waste generated in the EU. In 2019, it was accounted that buildings accounted for 57% of Africa's overall energy consumption and 32% of the continent's CO_2 emissions from its processes. This produces a greater percentage of waste, emissions, and materials usage (Aste et al., 2022). In all, buildings in 2020 were responsible for 36% of worldwide energy demand and 37% of energy-related CO_2 emissions (United Nations Environment Programme, 2021). Again, materials used in construction currently make up approximately 35% of all waste in the world and 50% of all solid waste that is produced annually on a global scale. As a result, global material scarcity would result if consumption exceeded resource regeneration (Mahpour, 2018; Ness and Xing, 2017). Since they adhere to the linear "take-make-dispose" paradigm of resource consumption, the vast majority of items are not even close to being circular-ready (Moreno et al., 2016).

To mitigate the adverse impacts of waste, it is crucial to take measures that both prevent or decrease its creation and manage it effectively. The concept of the "3R" principle emerged from the 2005 Ministerial Conference on the 3R Initiative in Tokyo, Japan, advocating for waste reduction, reuse, and recycling (Heshmati, 2017). As economies transition from linear to circular, these steps have evolved. Reike et al. (2018) introduced the "5R" principle within the circular economy (CE) literature, encompassing rethinking, reducing, reusing, repairing, and recycling (Tserng et al., 2021). Building on this, Zorpas (2020) proposed a comprehensive "10R" principle for waste management, which includes refusing, rethinking, reducing, reusing, repairing, refurbishing, remanufacturing, repurposing, recycling, and recovering. During the transition of countries toward a circular economy, waste management principles have continued to evolve, culminating in the inclusion of all 11Rs. These encompass refusing, rethinking, reducing, reusing, repairing, refurbishing, replace, remanufacturing, repurposing, recycling, and recovering (Amudjie et al., 2023).

A circular economy facilitates a continuous path toward sustainable progress. It emphasizes the reuse, recycling, replacement, protection, and valuation of resources at every stage of a product's lifecycle (Kirchherr et al., 2023). By recirculating products instead of discarding them after use, the circular economy retains product and material value more effectively than today's linear economic model. This approach reduces the demand for new materials and energy inputs, consequently alleviating environmental pressure across the product lifecycle, from resource extraction and production to end-of-life (De Schoenmakere and Gillabel, 2017). Furthermore, by minimizing waste generation, the circular economy can also contribute to a reduction in greenhouse gas emissions. Consequently, it offers a solution to unsustainable consumption patterns and presents a viable path toward a green economic recovery (Illankoon and Vithanage, 2023).

The designers of a product or service have a considerable obligation to influence the standard method that is already used in the construction of that product or service. The architectural decisions made at the outset of the design process have a significant impact on the final product (Bertino et al., 2019). The Royal Institute of British Architects (RIBA) terms this phase of the design process Concept Design. The project's design will affect the process's circularity and sustainability, which is why it's important to provide the customer with early visual representations of the design concepts (Fernandez-Antolin, et al., 2021). Therefore, when designing for a circular economy, it is essential to take into account various design strategies aimed at closed-loop systems, as they are a crucial factor in ensuring their effectiveness.

Given the above insight, Design for Circularity (DfC) is crucial to steer the construction industry towards circularity and sustainability. However, specific research to address, discuss and point out the key strategies for Design for Circularity (DfC) implementation which is becoming a core product design necessity in the Construction Industry (CI) is not evident in most existing literature. As such, the attention of researchers was drawn to this critical gap merited in this current study. To address this issue, the primary aim of this study is to investigate the key DfC strategies used in the construction industry through a mini-scoping review. Therefore, the DfC concept will be examined to determine the breadth of application of the term in the literature, its development over the past few years as well as to identify the key DfC strategies.

Scoping reviews are beneficial for examining scope, range, and clarifying key ideas in unresearched areas, emerging evidence, and areas lacking uniformity in approach and terminology (McMeekin et al., 2020). Thus, reports can be obtained on the types of evidence that address and inform practice in the field as well as the way the research has been conducted. Accordingly, the study uses a mini-scoping review to investigate key design for circularity (DfC) strategies used in the construction industry.

The paper is organized into six sections. In Section 2, the background of circular design is presented. Section 3 outlines the study's methodology, including its objectives, research design, and how findings will be discussed. Section 4 presents the results and discoveries from the literature search. Additionally, Section 5 delves into the insights derived from discussing the findings of the scoping review. Lastly, Section 6 concludes the paper by summarizing the analysis, offering recommendations, and addressing the study's limitations and potential future directions.

2.0 General Information and Background of Design for Circularity (DfC)

2.1 CE and The Construction Industry

CE is a novel approach to solving sustainability issues that prioritizes increasing the efficiency with which resources are reused rather than discarded (Zhang et al., 2019). To reduce the amount of waste produced by the linear economic model, which harms both the environment and human health, groups like the Ellen MacArthur Foundation and the World Resources Institute are pushing for a global transition away from it in favor of CE (D'Adamo, 2019). Furthermore, Benachio et al. (2020) establish that the goal of a CE in the Construction Industry is to conserve natural resources by reusing and recycling building components for as long as possible throughout a building's lifespan. Again, Yu et al. (2023) spell CE out as a holistic approach that involves the participation of both public and private stakeholders, which aims to preserve material value throughout a product's entire life cycle.

2.2 The concept of Design for circularity (DfC)

The construction industry stands out as one of the most resource-intensive and waste-heavy sectors in the global economy (Rose and Stegemann, 2018). It contributes to one-third of the world's carbon dioxide (CO_2) emissions and has a disproportionately negative impact on the environment (Martin and Perry, 2019). The life cycle of a building, including the manufacturing of materials, construction, use and maintenance, and eventual disposal or demolition, presents multiple stages where the building's components can have adverse environmental effects (Najjar et al., 2017).

Nie et al. (2023) underscores the critical role of decisions made during the design phase in preventing and reducing waste throughout a building's construction, usage, and demolition. Given the construction industry's significant contributions to greenhouse gas emissions and solid waste, it has become a central focus within the growing paradigm of the circular economy (CE) (Rajagopalan et al., 2021). The circular design aims to minimize waste across a product's entire life cycle by creating products and services that are not only functional but also constructed from high-quality components to ensure optimal performance with minimal environmental impact (Aho, 2016).

According to Pomponi and Moncaster (2017), Design for Circularity (DfC) emerges as the most applicable and effective circular building design strategy, particularly within the context of construction. In the realm of architecture, CE design goes beyond aesthetics and considers how a building is used. DfC envisions a building that aligns with CE principles in its design, planning, construction, management, maintenance, and eventual deconstruction. The core of circular design revolves around keeping materials and products within closed loops to prevent the loss of their inherent value. Life cycle loops like reuse, refurbishing, remanufacturing, and recycling promote resource efficiency (Medkova and Fifield, 2016).

Circular design and construction practices generate direct economic benefits, including reduced operational and maintenance costs, slower depreciation, increased asset value, and enhanced industry competitiveness by eliminating resource shortages and price volatility (Ghaffar et al., 2020). Additionally, the concept of Design for Circularity integrates the end-of-life phase into the initial design, with a focus on maximizing a building's useful lifespan (Giorgi et al., 2019). It aims to deliver goods or services that are not only functional and made from top-quality materials but also perform at their peak while minimizing their negative impact throughout their entire life cycle (Antonini et al., 2020). Therefore, the circular economy's design approach replaces the notion of "end-of-life" with "restoration," emphasizes the use of renewable energy, eliminates harmful chemicals that hinder reuse, and strives to eliminate waste.

Akhimien et al. (2021) highlight several benefits that the construction industry can gain from embracing circularity, including a reduced environmental footprint, less waste generation, and resilience against the adverse effects of market fluctuations, such as price increases and delays. In this context, the role of design is to encourage the reuse of construction products and materials, reduce the environmental impact of buildings, and expedite the regeneration of natural systems. It is widely acknowledged that engineering and design play a pivotal role in establishing processes that facilitate the reuse, recycling, or recovery of all material components, thereby reducing the volume and toxicity of waste that would otherwise end up in landfills (Varbanov and Walmsley, 2019). Kanters (2020) reiterates that the design phase holds significant sway over a project and that designers bear the responsibility of ensuring the functionality and longevity of building projects.

3.0 Materials and Methods

A method of reviewing literature, following a scoping review was conducted to enlighten and throw more light on the DfC strategies employed in the construction industry. Scoping reviews are conducted primarily to locate and arrange relevant information, and forms of evidence as well as to identify and explore factors or gaps associated with an existing body of literature (Munn et al., 2019; Peters et al., 2015). Before doing a full systematic review, scoping reviews can be thought of as an exploration of the research evidence that aims to synthesize and distribute study findings (Bradbury-Jones et al., 2022). The review methodology used the 5-step process recommended by Arksey and O'Malley (2005) that were:

Figure 1: Flow chart of Scoping review process (Authors Construct, 2023)

Using Figure 1 as a basis, the study adopted a search criterion to identify and retrieve relevant studies/papers against the PRISMA guidelines. The PRISMA guidelines were followed to locate, select, and report on the sources of literature (Peters et al., 2021). Thus, retrieve, examine, and present the results. The research question formulated looked at:

- What is known from the literature about the key design for circularity (DfC) strategies used in the construction industry?

The scoping review was conducted to source literature from databases such as Google Scholar and Scopus. These databases are suitable because they have proven useful in literature peer search, they provide access to a wider range of journals and citation analysis, and they encompass a substantial portion of the scientific disciplines (Munaro et al., 2020; Zientek et al., 2018). These electronic databases provided a compilation of literature as a representation of strategies to design for circularity in the construction industry. For relevant sources of literature to be obtained, the following search criteria were used:

- Search terms employed included: ‘design for circularity in construction’, ‘circularity in construction', 'circular building design', 'CE in the construction industry', 'CE design strategies'
- The article’s title had to do with CE in the construction industry or the built environment
- The article/publication should make mention of at least one DfC strategy explicitly related to the CE.

The literature obtained from the databases included peer-reviewed journal papers and books, for the scoping review to minimize bias, and ensure that selected studies had been exposed to analytical and review structure to promote a fair representation. To facilitate easy analysis and comprehension, only English-language articles were included.

3.1 Inclusion and Exclusion Criteria

Criteria for inclusion in the mini-scoping review were English language journal articles published between 2016 and 2023 to focus on recent trends. The most important ones were settled on to be used for this study titles, abstracts, and full texts of articles were read. Thus, only articles that targeted CE in building or built environments, circular building design, design strategies, or made mention of circularity were shortlisted.

Table 1: Criteria for study selection

Criterion	Inclusion	Exclusion
Language	English	Non-English articles
Database	Google Scholar, Scopus	Web pages and reports from research
Year of publication	2016-2023	Documents published before 2016
Publication Type	Journal, conference papers, or Scholarly peer-reviewed journal articles	Thesis, public reports, newspaper articles
Availability	Full text available	Abstracts only
Research direction	Articles that target CE in buildings/construction industry/built environment	Documents that do not include CE

Source: Author’s construct (2023)

4.0 Results

The search engines and the keywords employed for this study generated an extensive list of publications which were further analyzed resulting in the inclusion of nine publications for the study. As a result, the extracted data and their sources were listed in a spreadsheet in Microsoft Excel. Table 2, outlines nine of the studies that met the inclusion criteria for this review.

Table 2: Summary of Articles and DfC Strategies Included in Scoping Review

No.	Author	Title	DfC Strategies
1.	Yu et al. (2023)	Circularity information platform for the built environment.	• Design based on upcycling • predictive design for zero waste • design for disassembly
2.	Moreno et al. (2016)	A conceptual framework for circular design.	• Design for circular supplies • Design for resource conservation • Design for multiple cycles • Design for long-life use of products • Design for systems change
3.	Spreafico (2022)	An analysis of design strategies for the circular economy through life cycle assessment.	• Design for reducing wastes • Design for remanufacturing • Design for reuse • Design for using renewable energies • Design for recycling • Design for energy recovery • Design for recovering energy from waste • Design for disposal (using biodegradable materials)
4.	Munaro et al. (2019)	Proposal of a building material passport and its application feasibility to the wood frame constructive system in Brazil.	• Monitoring and controlling material flows while evaluating the impacts of resources • Designing taking into account the dynamism of the building during its life cycle • Developing stakeholder relationships in the construction value chain to incentivize them to enable a CE in the building construction industry.
5.	Dewagoda et al. (2022)	Design for Circularity: The Case of the Building Construction Industry.	Early building life cycle stage: • Design for reuse • Design for recycling End of life (EOL) stage: • design for disassembly (DfD) • design for adaptability • design for flexibility • Offsite construction technologies; however, circularity is not to be subsumed as modularity
6.	Dokter et al. (2021)	How circular is current design practice? Investigating perspectives across industrial design and architecture in the transition towards a circular economy.	• Business model design • Lifecycle perspective design • Use of Data in Design • Design for material reuse • Circular design brief • Design of systems and services

7.	Chen et al. (2022)	Revamping construction supply chain processes with circular economy strategies: A systematic literature review.	• Design with LCA • Design with reused materials • Design with recycled materials • Design for deconstruction/disassembly
8.	Eberhardt et al. (2022)	Building design and construction strategies for a circular economy.	• Assembly/Disassembly • Material selection • Adaptability • Modularity • Secondary materials • Prefabrication • Standardization • Optimized shapes/dimensions • Durability • Component and material optimization • Accessibility • Reusing existing building/components/materials • Layer independence • Material storage • Symbiosis/sharing • Short use
9.	Cruz Rios et al. (2021)	Barriers and enablers to circular building design in the US: an empirical study.	Narrowing resource loops • Preserve and extend existing resources • Dematerialization Slowing resource loops • Design for resource integrity • Long use: Design for physical durability, Design for emotional durability • Extended use: Design for maintenance, Design for upgrading, design for disassembly • Recovery: Design for reuse, Design for repair, design for refurbishment, design for remanufacturing, design for disassembly Closing loops • Design for biological cycles: use biodegradable materials, use safe and healthy materials and processes • Design for technical cycles: a design for upcycling, design for depolymerization and design for

			disassembly

5.0 Discussion

This scoping review article obtained more than forty circular building design strategies. Across the identified literature, these strategies were found to be interpreted, implemented and practiced in different ways. There is an urgent need for the construction industry to reduce its negative effects on the environment through the use of circular design after the alarming rate of environmental destruction was brought to light by the findings of the Ellen MacArthur Foundation (EMF, 2017). Thus, it is clear from the existing literature that current research and practice within the building industry have mostly concentrated on the following to narrow the gap in identifying the key design for circularity strategies:

Design for material reuse: This strategy focuses on plowing back repurposed or recycled materials with a second life, reducing the demand for new materials and minimizing waste. Such materials should be tested for durability, adaptability, and compatibility to facilitate their reuse (Dewagoda et al., 2022; Dokter et al., 2021). Designers/architects must therefore raise their awareness of the necessity to adjust design requirements to account for numerous future building situations to ensure multiple reuses of components and materials (Dams et al., 2021; Durmisevic, 2019)

Design for reducing waste: Inadequate design decisions by the design team through the construction of works, increases more waste. As a result, decisions about building materials, waste avoidance, and waste-efficient operations should be taken early in the design process (Shooshtarian et al., 2022). As a result, this strategy has the goal of making beneficial use of materials, embracing lean construction methods and employing standardization techniques to reduce waste at source.

Design for recycling: Recycling is the process of recovering usable components from waste and reusing them in production (Mhatre et al., 2021). Hence, designs that have recycled material choice or incorporate building materials that are easily recycled reduces the negative construction works environment (Chen et al., 2022). Also, Spreafico (2022), reveals recycling puts elements back into products without impairing their functionality. Therefore, it supports environmental sustainability by decreasing the demand for new materials and limiting the reintroduction of virgin resources.

Design for deconstruction/disassembly: DfD is the practice of planning and designing structures with their eventual dismantling and reuse in mind (Pittri et al., 2023). Deconstruction, unlike disassembly, involves the removal of a building's structural elements before they may be dismantled. Hence, the breaking down of a structure into individual components that can be reused (O'Grady et al., 2021).

Design for disposal: Although circularity strives to reduce waste, materials and components may eventually deteriorate and require disposal. It is then important to design for disposal to examine how such discarded materials will influence the environment, what disposal choices are available, and how biodegradability can be incorporated into the design (Spreafico, 2022; Cruz Rios et al., 2021).

Design for adaptability: To limit the quantity of new construction necessary and the number of old structures that must be demolished, designers are increasingly stressing design for adaption (Dewagoda et al., 2022). Buildings can be repurposed, altered, or modified over time to accommodate changing user needs and requirements, as well as new environmental circumstances, by including characteristics of flexible design such as demountable obstacles or adaptable layouts (Askar et al., 2022).

Design with Life Cycle Assessment (LCA): Design with LCA strategy aids to minimize building costs and material utilization by assessing the benefits and drawbacks of using construction and demolition waste in circular construction materials (Gomis et al., 2022). Also, LCA speeds up design processes and identifies potential environmental impact reductions (Chen et al. 2022).

Design with off-site technologies: The goal of this strategy is to guarantee that buildings are constructed using factory-standard components and materials to reduce onsite waste, and optimize the use of resources (Kedir et al., 2023).

6.0 CONCLUSION

Despite researchers' efforts, papers may be excluded from the review due to the database in which they are stored. The use of different software such as COVIDENCE and Rayyan may reveal different content, to supplement manual search techniques. Furthermore, the inclusion of papers written in English only may not adequately represent the breadth of literature on a platform that is accessed worldwide. From Table 2, the findings of this mini-scoping review indicate that there are relatively few studies evaluating circular design strategies. The mini-scoping review highlighted the following as key strategies: *Design for material reuse, Design for reducing waste, Design for recycling, Design for deconstruction/disassembly, Design for disposal, Design for adaptability, Design with Life Cycle Assessment (LCA) and Design with off-site technologies* that account for circularity in the construction, which have been explained with the aid of pertinent studies. The study, thus sheds light on DfC as a concept that is becoming more and more crucial and has the potential to lessen the ecological impact of the construction sector. Again, these circular design strategies encourages implementation of eco-friendly methods that reduce the environmental impact of construction projects. It further emphasises the use of durable materials and construction techniques that extend the lifespan of a building. Moreover, implementation of these design strategies might involve adherence to specific regulations and certifications related to sustainability. This will ensure that projects meet these requirements and guide the design team in achieving certifications like LEED (Leadership in Energy and Environmental Design) or BREEAM (Building Research Establishment Environmental Assessment Method).

It is further suggested that future research emphasizes the development of existing ones and the integration of existing strategies in the construction industry processes. Again, there is a need for further collaboration between design professionals and other CI stakeholders (engineers, suppliers, and contractors) to see to it that these strategies are prioritized to lessen the negative impacts of the construction processes on the environment. Also, a rating system for these strategies should be devised to determine which of the strategies has the largest impact, why, and in what way. In conclusion, circular building design in the construction industry is an approach that applies circular economy principles to optimize resource efficiency and minimize waste. As a result, to successfully implement circular building design, collaboration and involvement of various stakeholders such as the scientific community and the construction professionals are essential. They can develop strategies, regulations, and incentives to promote circular building design.

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