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Implementing Circular Economy Strategies in Buildings—From Theory to Practice

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Abstract: Population growth, along with a rapid urban expansion, is imposing a heavy pressure on the planet's finite resources. It is widely acknowledged that the building industry consumes large amounts of raw materials while generating waste and emissions. To set apart economic growth from environmental repercussions, the Circular Economy (CE) arose as an innovative paradigm that can offer a fast-track towards a sustainable built environment. This paper will tackle a research gap that academia and policymakers often highlighted, which is how can we apply CE to assets that are predominantly meant to be demolished and their resources wasted when they reach their end-of-life. Globally, the paradigm aims at erasing the waste concept, relying on renewable and regenerative sources, and keeping the materials, components, and systems in use at their highest value as long as possible. The concept's implementation would attempt to consider the built environment as a closed-loop system wherein resources are viewed as a scarce commodity. Although the CE seems straightforward, translating the circular thinking to the building level might be a hardship. The following paper will attempt to shed light on how to promote CE in buildings that will ultimately lead to healthier, more efficient, and more sustainable cities on a broader scale. The proposed framework considers CE implementation strategies throughout the building's lifecycle and mainly deals with three innovative aspects: wise resource management, building design approaches, and digitalization of the building industry. In this sense, this study will explore these game-changing factors that are considered paramount to concretize the concept in practice and provide a smooth pathway for CE uptake in buildings.

Keywords: circular economy; circular building; implementation strategies; design strategies; circular resource flows

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1. Introduction

The building industry plays a vital role in the economic prosperity and social welfare [1]. However, economic progress has led to significant environmental damage, and the construction industry accounts for 33% of greenhouse gas emissions, 40% of resource consumption, and 40% of waste generation [2]. Former sustainability-related practices have come short in terms of managing the end-of-life scenario of resources by mainly focusing on recycling rather than adopting a holistic approach that would enable more significant environmental benefits [3,4].

With the emergence of the Circular Economy (CE) concept, professionals, academia, and policymakers have regarded the paradigm as a suitable response to this resource-intensive sector. The building sector is one of the five priority sectors in the European CE package, which may prompt this particular branch into developing new eco-technologies [5,6]. The CE is increasingly gaining recognition within the construction industry [7]. It is considered an innovative practice to foster sustainability in a systematic way and move away from the basic linear economy model, which consists of "extract, use, and landfill". It encourages the reduction of raw materials inputs, relies on renewable sources, and eliminate waste from the system [8]. Recent studies have focused on recycling Construction and Demolition Waste (C&DW) with little consideration on the reuse of products, resulting in the reduction of reclaimed materials [9,10]. The avoidance of C&DW is becoming more adopted, whereas further studies must be conducted mainly at the design stages to ensure better end-of-life scenarios [11–13]. While, typically, contemporary buildings are not designed for deconstruction [14–17], the concept of reusing their assets after their end-of-life should be considered for achieving higher levels of environmental performance with less material input [18]. Others have also stressed the significance of the building stock, which represents the most critical part of the produced (human-made) wealth of industrialized societies [19,20], and have underlined the urgent need to decrease material use and increase the quality and durability of the building stock as a resource [2].

Nevertheless, implementing CE strategies in buildings promises to be hindered by the ambiguity surrounding the concept. Despite the fact that the research output contributing to the development of a circular built environment is considerably increasing [21,22], there is still a lack of a thorough study that entails various facets of CE in buildings [7]. The present research will describe CE background, strategies, and approaches that can be applied in the construction industry according to recent studies, in an attempt to link theory to practice and provide better insights on the concept's uptake at the building level.

2. Materials and Methods

This research sought to pinpoint key-strategies that are in line with the idea of CE and that can be implemented in buildings. Numerous studies have already tackled this aspect; however, the focus was mainly put on a single feature (e.g., materials and components, energy, or design strategies) or merely related to C&DW practices [7]. This exploratory research will provide a better understanding to a common research question, which is how CE principles can be applied to buildings. This is done through analyzing CE-related articles and reports related to resource management, design strategies, Building Information Modelling (BIM) and Materials Passports applications, and case-studies to provide a framework that holistically takes into account CE principles throughout the building's lifecycles.

In this context, the article will outline CE principles and the origins of the paradigm (Section 3), describe how resources should be used and managed from a CE perspective in a closed-loop system (Section 4), identify CE design strategies (Section 5), highlight the need for digitizing the building sector (Section 6), showcase practical case-studies wherein CE strategies have been implemented (Section 7), and, finally, conclude with a framework, summary, limitations, and further recommendations (Section 8).

3. CE Background and Principles in the Built Environment

The need for better management of resources that are becoming scarcer, and dire environmental impacts has urged academia and policymakers to provide a new pattern to move away from the economic model adopted since the industrial revolution. The idea of CE was refined throughout the last century to be widely acknowledged during the previous decade. Nevertheless, the roots of CE are still ambiguous and cannot precisely be pinned to a single research. One common agreement is that CE is deeply rooted in numerous schools of thought.

Walter Stahel, an architect and industrial analyst, together with Genevieve Reday, released the research report named "*The potential for substituting Manpower for Energy*," which focuses on an economy in loops and its outcomes on job creation, economic competitiveness, resource savings, and waste prevention [23]. Stahel also worked on a new approach to production and processes, the "closed-loop". It aims at promoting product-life extension, long-life goods, reconditioning activities, and waste prevention. His latest work focuses on "Performance economy" [24] where he claims the importance of selling services instead of products, which is considered a key feature of CE.

The Cradle-to-Cradle concept was developed by the German chemist and visionary Michael Braungart and the American architect Bill McDonough [25]. The Cradle-to-Cradle concept considers all materials involved in industrial processes as nutrients from two categories: technical and biological. This framework deals with the design for effectiveness and positive impacts while reducing negative ones resulting from design for efficiency [26].

The industrial ecology focuses on material and energy flows through the industrial systems [27]. The concept arose as a solution to resource scarcity and high material cost. This approach intends to create closed-loop strategies that promote waste as an input to eliminate the notion of undesirable by-products while promoting regenerative use of resources [28]. Consequently, wastes and resources stream in a circular way between the different ecosystem components with renewable energy supplying those cycles [29].

Back in the 1970s, the American professor, John Tillman Lyle, challenged his students to come up with an idea for society by adopting the following approach: "daily actives are based on the value of living within the limits of available renewable resources without environment degradation" [30]. The idea of regenerative design relies on developing buildings and cities to regenerate ecosystems [31]. This concept has been formulated earlier for agriculture and has its roots in bioregionalism and permaculture, but Lyle expanded it to the entire social-ecological system to broaden its ability to enhance its potential [32].

Among the front-runners in terms of CE implementation, the Chinese government started to show an increasing interest in the concept by implementing explicit policies back in 2002. Later on, research on CE increased exponentially through the CE promotion law in 2009, to stimulate cleaner production, develop eco-industrial parks, and cope with the rapid urbanization [33,34]. In Europe, the Ellen MacArthur Foundation's creation and the release of the action plan by the European Commission accelerated the transition towards the CE by promoting renewable energy, designing out waste and closed-loop systems to retain material's value circulating in the economy.

Initially, the CE-related Chinese literature framed the concept around the 3R's principles, Reduce, Reuse, and, Recycle [35–37]. Wherein, "Reduce" refers to the action of minimizing inputs and outputs such as raw materials and waste, "Reuse" is the operation of using a product again for the same purpose when it reaches its end-of-life, and "Recycle" is the process of recovering waste to manufacture a new product.

The 3R's principles were later extended to a 9R's framework to encompass more actions and achieve a transition towards CE more effectively. The R-list includes three key-strategies to increase circularity and innovation in product design [38]. The first strategy stresses the need for wiser product manufacturing and includes three actions:

Refuse: Depreciate a product with dire impacts and proposing a different one with identical or better functions and fewer impacts;
Rethink: Intensify the product use and adopt smarter strategies as sharing economy or products with multiple functions; and,
Reduce: Decrease virgin materials and energy consumption while enhancing efficiency.
The second strategy encourages product lifespan extension and consists of:
Reuse: Reuse a discarded product that keeps the same functions by another user;
Repair: Fix a damaged product to give back its initial performance;
Refurbish: Renovate an outdated product to make it as a new one;
Remanufacture: Make a product using parts from a damaged product that had the same functions; and,
Repurpose: Make a product using parts from a damaged product that had different functions.

The last and least favored strategy comprises:

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,
Recover: A process of retrieving heat, electricity, or fuel from non-recyclable materials by incineration.

The Ellen MacArthur Foundation outlined three principles to embrace CE [39]:

Principle 1: "to preserve and enhance natural capital by controlling finite stocks and balancing renewable resource flows."

Principle 2: "to optimize resource yields by circulating products, components, and materials at the highest utility at all times in both technical and biological cycles."

Principle 3: "to foster system effectiveness by revealing and designing out negative externalities."

Scaling up the CE principles to buildings holds the promise to attenuate negative environmental impacts by keeping materials and components in use and guarantying their reuse when the building reaches its end-of-life. Designing for a CE implies designing for adaptability, flexibility, and disassembly to enable reversibility and salvage the value of building's products. This practice will decrease the use of raw materials and reduce waste generation up from the design stage.

The European commission has recently released a report entitled "Circular Economy principles for buildings design" wherein the macro-objectives "Resource efficient and circular material life cycles" of the assessment methodology Level(s) has been linked to three CE strategies, which are durability and extended lifespans of building materials, adaptability, and efficient waste management [40]. In the same context, the Ellen MacArthur foundation outlined in their report two different cycles for reintroducing materials to the loop and optimizing resource consumption, technical and biological [41]. Biological materials are those elements that can be put back to the biosphere safely at their end-of-life. Technical materials are human-made elements that be reused, repaired refurbished, recycle, and incinerated at their end-of-life. From these principles, the Circular Building emerged as a new practice that embed every aspect of the concept. it can be defined as "a building that is designed, planned, built, operated, maintained, and deconstructed in a manner consistent with CE principles" [42].

Nevertheless, merging CE principles to the built environment is hampered by the inherent complexity of the concept, given the fact that buildings are predominantly constructed to be demolished at their end-of-life instead of deconstructing them or adapting them to users' needs. Moreover, design strategies and materials and components selection are crucial strategies to ensure an optimal CE implementation. Preference is given to low embodied carbon and energy materials with higher quality that can embrace reversibility without compromising building's performances and user's comfort.

4. CE Strategies for Energy, Materials, and Water

Natural resources are substantially used and consumed throughout the buildings' life stages as this industry is responsible for around 30% of water use and 40% of raw materials extraction and energy consumption [2,43,44]. By adopting particular CE strategies, savings may occur by creating proper systems to retain value and keep the resources flowing in a circular manner [45]. This approach would close materials and components, energy, and water loops and minimize the associated potential environmental impacts [46].

The life cycle of circular buildings should be a closed-loop system wherein components and materials are optimally used and retained at their highest value (Figure 1). The technical cycle consists of selecting materials and components that can be maintained to extend their service-life by reusing, refurbishing, repairing, and remanufacturing [21]. At the same time, recycling and incineration are final strategies. While, on the other hand, the biological cycle involves natural materials that can be biodegradable or compostable at their end of life (e.g., bio-based materials) [47].

According to Pomponi and Moncaster [42] circular buildings encompass green and sustainability strategies. The environmental footprint of materials and components should be as minimal as possible. It is preferable to select locally sourced materials to reduce emissions due to transportation and stimulate the local economy. Low embodied energy and carbon materials that are abundant, renewable, and pure are fundamental strategies to achieve eco-friendly structures with a minimal input of raw materials within a circular flow system.

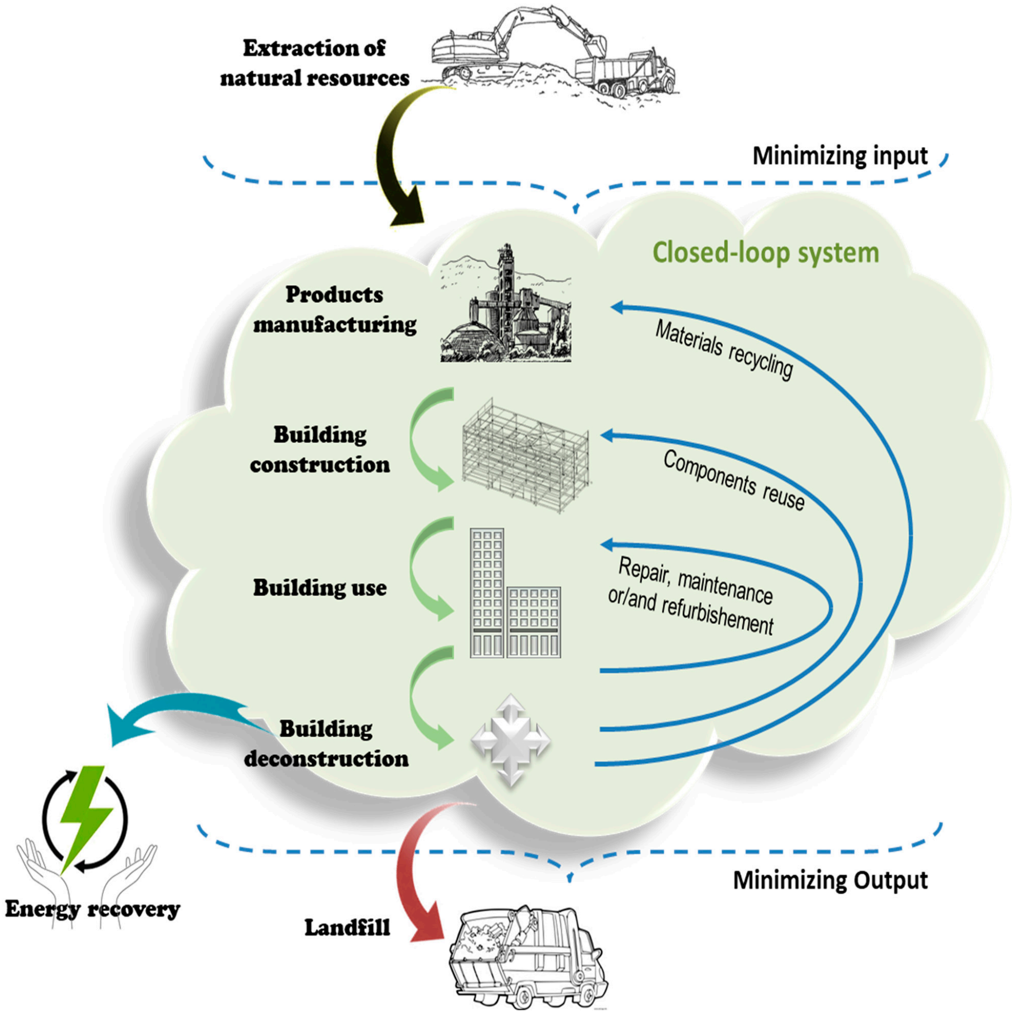

Figure 1. Closing materials and components loops in buildings.

Circular building design entails adaptability, flexibility, and deconstruction at its core. Materials and components need to endure numerous life cycles, depending on the use purpose. Therefore, durability and resilience are two features that need to be taken into account when selecting materials and components to ensure no loss in quality or value over time and use-cycles.

Throughout the building's lifecycle, energy is substantially used and consumed, from materials extraction and processing to the building's construction, operation, and demolition/deconstruction phases [48]. Recent policies regarding Nearly Zero-Energy Buildings (NZEB) challenge practitioners to produce buildings with high energy efficiency [49]. In this context, circular buildings can achieve energy neutrality and even produce an excess of energy through design and on-site renewable energy production [50,51]. The overall energy consumption of buildings is mainly allocated to building operations, followed by embodied energy [52]. The use of materials and components that are energy-intensive increases the buildings embodied energy and, therefore, the life cycle energy consumption. In Europe, energy consumption related to building products ranges from 5% to 10% [53]. Another critical parameter to reduce energy consumption during the use phase is enhancing the building's thermal insulation. High-quality materials are needed to provide the necessary services and thermal comfort for the users [54]. Hence, materials selection and contextual building design and layout should be considered to reduce energy consumption throughout the building's life-cycle.

With the global urbanization, water is getting scarcer since this resource is encountering an increasing demand, and many researchers have predicted a freshwater crisis by the end of this century [55]. In all buildings' life cycle, water is considerably used and consumed by all building stakeholders. Similarly to energy consumption, water is most consumed during the operation phase by building users, followed by buildings' embodied water [56]. Water is used to manufacture several building materials, such as concrete and cement-based materials, ceramics, coatings, and steel. Selecting low embodied water materials will eventually decrease the building's water footprint. Fidar et al. [57] investigated water-efficient microcomponents' use to reduce the water consumption in residential buildings and concluded that there is a linear relationship between water consumption and energy use [57,58]. The building design should also be adapted to the context of its location to embrace more water efficiency. Reaching water efficiency in circular buildings can be achieved during the use-phase by harvesting rainwater and reusing greywater.

5. Design for CE

A critical aspect of the CE thinking is to provide the building's materials, components, and systems a second life of use when the building itself reaches its end-of-life. A specific set of design strategies should be followed by adopting a holistic approach to enable reversibility, adaptability, and flexibility. This section will cover different design strategies that could be put under the umbrella of designing for CE (DfCE).

Over the past decades, several studies have highlighted the multiple benefits of building's disassembly [59–64]. These studies were driven by the environmental and economic benefits resulting from designing for further reuse and recycling to cut down demolition costs and slow down resource consumption pressure. However, with CE's emergence, these practices gained more attention as they matched the circular thinking for designing out waste and creating a closed-loop resource flow.

In this sense, Crowther [59] 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 [59]. Similarly, Ciarimboli & Guy [65] framed DfD principles around ease of deconstruction of building elements, eradicating chemical links and relying on mechanical connections that are accessible, dry construction, providing guidelines to support safe deconstruction, and selecting suitable materials for the process.

One of the most crucial parameters in DfD is the choice of the construction technology and how building elements will be assembled and disassembled. Materials should be eligible for embracing CE principles such as reuse, refurbish, repair, and higher purity to limit quality loss during the assembly/disassembly process. Unlike steel and timber, concrete has been overlooked when it comes to DfD, given the numerous challenges to disassemble concrete elements [60]. Offsite constructions and modularity are important features to consider while assembling components. In his book "*Building in layers*" Brandt's work has been paramount to current strategies to DfCE [66]. The author described buildings as separate but somewhat interlinked layers with their own technical and functional lifespan. Brand's widely-known model includes six layers with different life-spans [66,67]:

1—Site: the location of the building;

2—Structure: the skeleton of the building including the foundation and load-bearing elements;

3—Skin: Building elements in contact with the external environment such as façade and roof;

4—Services: the pipe, wires, energy, and heating systems;

5—Space: the internal fit-out like walls and floors;

6—Stuff: The rest of the internal fit-out, including the furniture and lighting.

Schmidt III & Austin [68] stretched this building system decomposition to cover the Surroundings and Social as a new 8S model.

Adaptability is another characteristic that has been linked to DfCE [69,70]. Addis and Schouten [71] stressed the difference between adaptability and flexibility and defined a flexible building as "a building that has been designed to allow easy rearrangement of its internal fit-out and arrangement to suit the changing needs of occupants," whereas an adaptable building is "a building that has been designed with thought of how it might be easily altered to prolong its life." On the other hand, Moffatt and Russel [72] included flexibility as a sub-strategy to design for adaptability, convertibility, and expandability. According to the authors, adaptable buildings should be maintainable, versatile, simple in design, and upgradable to accommodate user's desires with minimum quality loss and environmental impacts [72]. In the same context, Durmisevic & Brouwer [73] described three dimensions of transformation: spatial transformation, structural transformation, and element and material transformation.

Disassembling sections and parts from buildings into components and allowing their reassembling in a new combination is a better alternative to destroying buildings and systems from economic and environmental standpoints [45,64,74]. Practitioners and academia need to learn from the past to design for the future and adopt a DfCE strategy, since CE is deeply rooted on several schools of thought and consequently englobes numerous design strategies (Figure 2). It is noteworthy that designers should also consider resource flows in buildings throughout its life cycle. As discussed in the previous section, a neat selection of materials with low embodied energy and carbon with minimal water use throughout their life cycle is crucial to keep positive environmental impacts. Water and energy should be considered during the design phase to produce buildings that optimise resource flows without compromising overall quality and comfort for the building users.

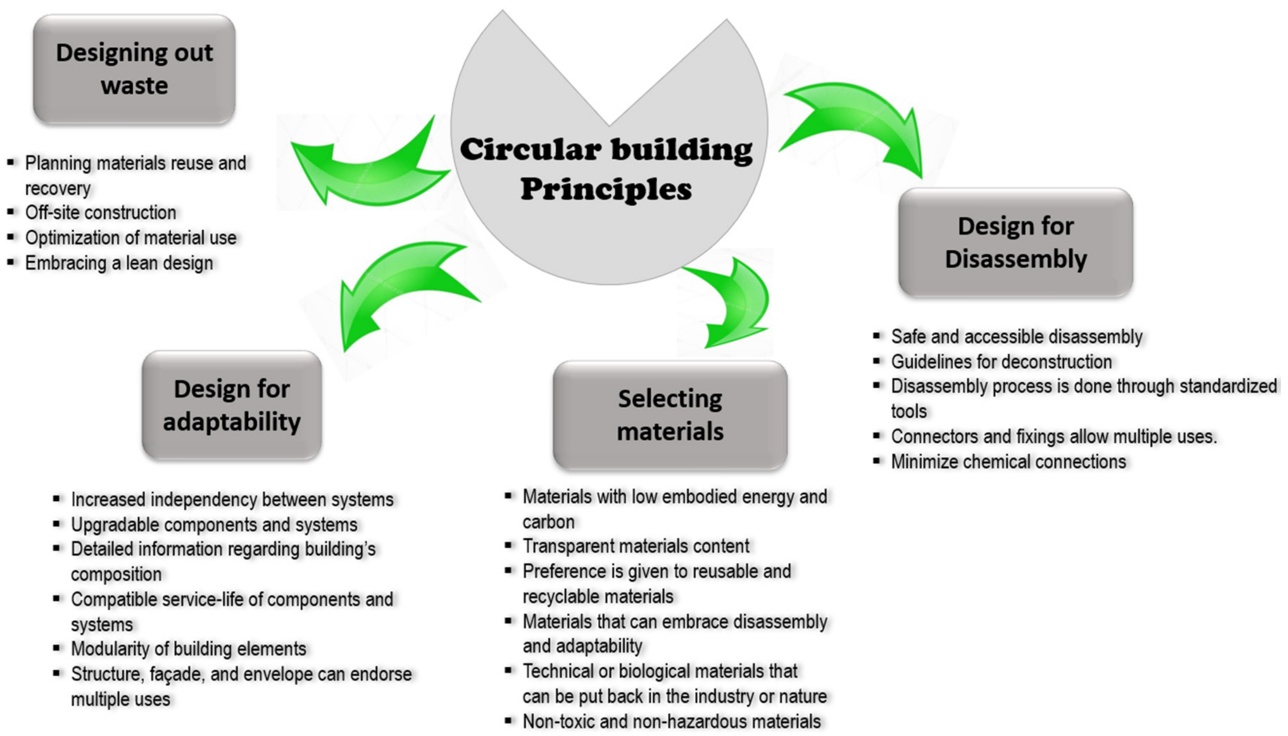

Figure 2. Design for Circular Economy.

6. Data Relevance for CE in Buildings

With the technological advances, data are becoming an essential asset for the construction industry to manage buildings' performances from the design stages until the end-of-life. Specific information is required to ensure the maintenance of a building and the technical life of all in-use materials. Tracking resource flows will allow building stakeholders to get deeper insights into the resource input-output. For the time being, the most significant challenge on the urban level is the generation of knowledge and data on the material composition of buildings [75]. Digitizing the built environment is regarded as a fast-track approach to implementing CE in the building sector. Keeping track of materials through specific datasets will support materials reuse once they reach their end-of-life, which will smoothen value retention. For materials and components, related information can be stored in a "Material passport" that will be shared with all building's stakeholders [76]. The Material Passport (MP) was developed during the EU-funded project "BAMB" to support circular building design, smoothen circular building materials selection, and extend their lives while keeping their value [77].

Comprehensive and accurate data can enhance decision-making, manage financial risk, and monitor environmental impacts. The MP provides qualitative and quantitative information regarding physical, chemical, and biological properties of materials composition, allowing practitioners to select building products that are safe to humans and ecosystems whilst taking into account CE principles. MP comprises different hierarchy levels, from materials, components, products, systems, and buildings, to describe specific features for value recovery and reversibility [78].

The Building Information Management (BIM) is a computational methodology that digitally models buildings to provide the construction stakeholders with valuable information to aid decision-making throughout the building's life cycle [79]. Understanding the purpose of BIM will support applying the planned strategy throughout the asset's life cycle [80,81]. In the context of CE, BIM can be considered as an approach to minimize waste throughout the building's life cycle [82,83]. However, BIM is seldomly used for managing buildings when they reach their end-of-life [82]. Recent studies have attempted to link MP to BIM to compile data on building materials characteristics and assess their recyclability and environmental impacts [75,76] or reuse waste as a novel construction material [84]. Nonetheless, research regarding MPs' integration into BIM is still in its early stage and requires more profound commitment from the construction industry. Digitizing the building industry will still face several obstacles such as the amount of data that must be generated, their quality, and the reliability of the used data, which will require standardization, collaboration, and transparency from the building stakeholders along the value chain [35].

7. Real-Life CE Implementation and Case-Studies

This section presents some success stories of CE implementation in buildings to provides concrete examples of current worldwide CE practices. One of the first projects to adopt CE strategies is the project Circular Building in London developed by Arup, which was driven by the challenge of applying CE principles to the built environment [85]. The building's design was inspired by the Brand's 6S model consisting of site, structure, skin, services, space plan, and stuff. For the structure, reclaimed steel was used as a material that can be reusable after deconstructing the prototype and put back into the loop. The project designers tried to put together a structure with simple and accessible bolts that will not hinder disassembly and embrace flexibility and adaptability. Regarding the building's skin, engineers used a softwood that has the needed durability to sustain different use-cycles. All the products involved in the building's layers were sustainably sourced, and most of them contain recovered materials and are eligible for reuse or recycling at their end-of-life. These materials are healthy both to humans and the environment and have a low embodied carbon and energy. The circular building was equipped with sensors to generate valuable data to control and adjust the indoor environment quality, namely lighting, temperature, and air quality to measure critical parameters.

The first building project to rely on MP was the Brummen Town Hall [86]. The building was designed for future disassembly over a historic structure from the 19th century building restored beforehand. The materials used are in line with the CE principles and can be further dismantled to be relocated and used into a new structure. As the building was designed for a service life of 20 years, the materials passport plays a crucial role in this project, namely, to keep track of involved materials and components to facilitate their reuse.

Likewise, the renovation of the headquarters of the energy grid company Alliander, located in Duiven, The Netherlands, relied on MP to store valuable information regarding their origin and their further reuse [51,86]. Additionally, the building is energy positive, which means that it generates more energy than it requires. It has solar panels and underground water for thermal storage. The project used a minimum quantity of raw materials and used recycled wood and steel. Another example of materials reuse is the Quay Quarter Tower redesign located in Sydney, Australia, by reusing an existing structure. Half of the building resources are reclaimed from an existing structure, which substantially decreased the associated time, costs, and environmental impacts.

Several case-studies across the globe attempted to concretize CE principles and provide real-life examples of how the construction industry can apply the paradigm shift. However, numerous challenges were noticed along the way. For instance, selecting the right building materials and components proved to be crucial for designers to embed circularity along the value chain [69,86].

In spite of the recent CE-related studies at the building level, intensive research is needed to accurately quantify the environmental, economic, and social benefits of applying CE in these entities. Considering an office building as a case-study, Eberhardt et al. [64] used a simplified allocation method to measure environmental impacts of disassembly and concluded that several parameters greatly influenced the findings such as the type of materials used, the reuse cycles, and building's service life. Similarly, Brambilla el al. [18] assessed and compared the environmental impacts of different structural composite floor systems and found out that one that was designed for disassembly was identified as the most environmentally friendly compared to the conventional scenario. These positive results have been further supported by Minunno et al. [4] who found out that a building designed for disassembly allows for reusing 62% of its mass, which will result in a reducing 88% of the emissions.

Although numerous studies have highlighted the environmental benefits of CE in buildings, several obstacles and barriers may slow down the momentum. A lack of governmental support through financial support and CE-related instruments is often highlighted as the main barrier for a greater CE uptake [22,87–89]. Additionally, construction professionals have encountered a lack of collaboration and obstacles to gather relevant data from materials suppliers [86]. Furthermore, these types of innovative projects require close management to keep the expected objective aligned. Workers, clients, team members and other building stakeholders will need to have a different mindset to embed circularity throughout the project life cycle.

8. Conclusions

With the population growth and the rapid urbanization, the building industry is imposing heavy environmental damage to the biosphere by consuming massive amounts of resources and generating considerable waste. With the emergence of the CE, construction stakeholders are considering adopting the paradigm and implementing its principles in building practices. Embracing these principles will require a paradigm shift towards sustainable production and use, a predictable end-of-life scenario of buildings, and a holistic approach to create a closed-loop system and adopt a wise resource management.

The objective of this paper is to explore the current theory regarding CE and develop a framework that introduces tangible strategies throughout the building's lifecycle (Figure 3).

Adopting CE principles in the built environment can reduce the consumption of resources and waste production, retain the value of resources as long as possible within the system, and reintroduce resources into the use phase through particular strategies. One critical approach to embed circularity is to select suitable construction materials with low embodied energy and carbon that can enable deconstruction and other design strategies in line with the CE principles. Circular building design should encompass low energy and water footprints and optimize the use of these resources in the operation phase. Energy efficiency practices and local and renewable energy sources are valuable approaches to consider along with CE principles to attain energy neutrality. Similarly, water use and consumption can be minimized through an adequate building design and reuse and harvesting systems for rainwater and wastewater. A valuable approach would be monitoring resource use and consumption in the operational phase, which can provide relevant insights to buildings actors and allow to adjust resource flows and reach higher levels of resource efficiency.

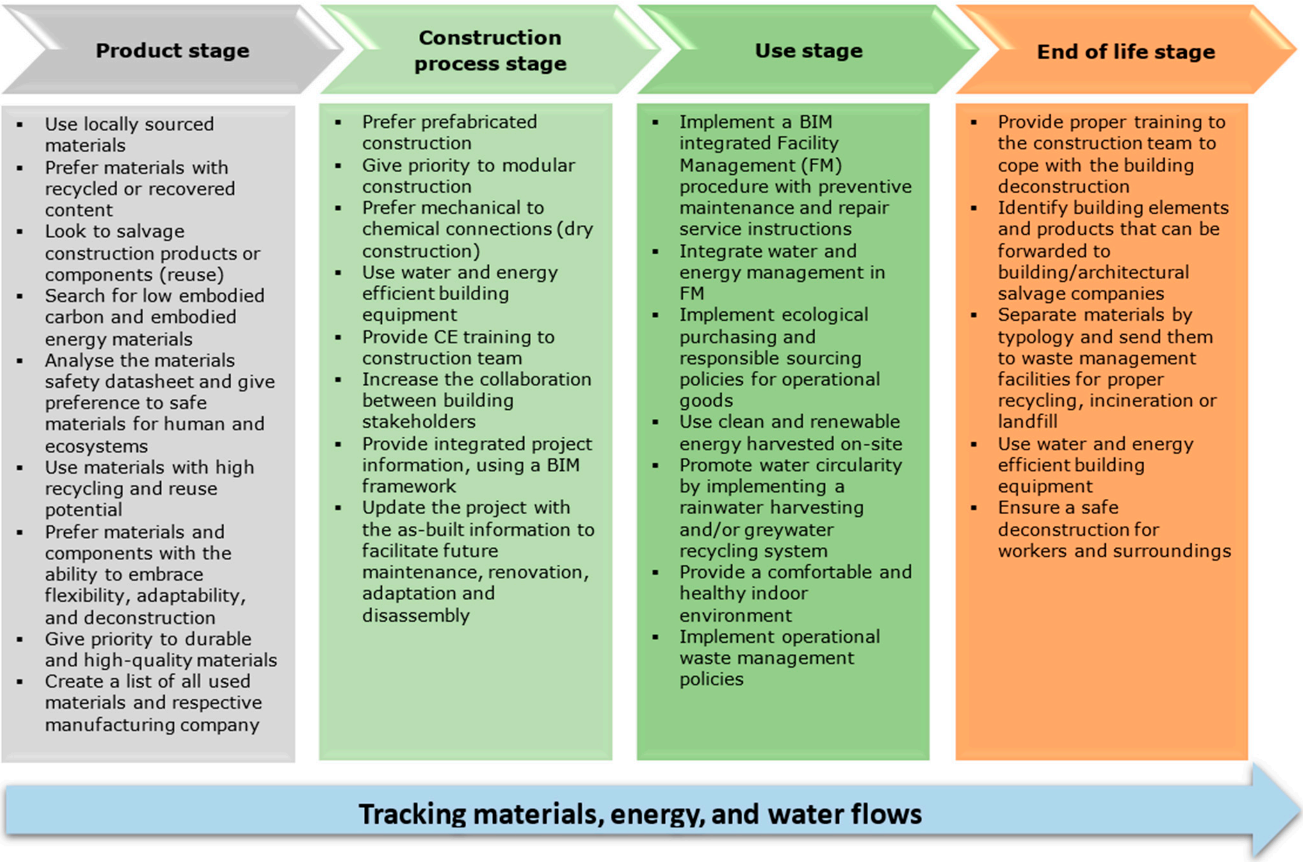

Figure 3. A framework for CE implementation throughout the building's life stages.

Several studies highlighted the need for design strategies that can enable material reusability and recyclability during the past two decades. With the increasing interest that CE is gaining, these particular design strategies have been encapsulated under the paradigm's principles. They matched the same objectives of value retention throughout several uses. To ensure the quality of materials and components and describe their specific characteristics, several studies have proposed integrating Materials Passports to the Building Information Management, which will allow building stakeholders to track materials, understand their origins, and assess their quality.

Finally, the CE aims to redefine the construction industry and challenge designers to reconsider how they design buildings and take into account their end-of-life scenario. Although numerous case-studies went beyond recycling to apply CE core principles, there are still several obstacles along the way (e.g., lack of economic incentives, lack of governmental support, the misconception regarding reused and recycled materials). These obstacles will eventually delay the transition towards a circular built environment and require a particular understanding of inevitable trade-offs.

Although, this study attempted to outline a framework for CE implementation in buildings, some limitations need to be addressed. The study can further be enhanced through a case-study to consider the local context or with a more sophisticated methodology, which will allow a broader scope and more concrete conclusions. Further research is also needed to quantify the economic and social benefits of implementing CE strategies in buildings.

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