Circular Building Strategies: A Categorization Framework

Citation for the original published paper (version of record):
Wöhler, A., Hollberg, A., Rosado, L. et al (2024). Circular Building Strategies: A Categorization Framework. IOP Conference Series: Earth and Environmental Science, 1363(1).
http://dx.doi.org/10.1088/1755-1315/1363/1/012038

(article starts on next page)

Circular Building Strategies: A Categorization Framework

A Wöhler[1], A Hollberg[1], L Rosado[1], and H Wallbaum[1]

[1]Department of Architecture and Civil Engineering, Chalmers University of Technology, Gothenburg, Sweden

Corresponding author: wohler@chalmers.se

Abstract. The concept of Circular Economy (CE) has been gaining increasing attention in the context of the built environment in recent years. Many different circular strategies for buildings, such as reusing structures, Design for Disassembly and Adaptability, have been frequently discussed in the literature, but a clear definition and framework are lacking. This study provides a categorization framework for circular strategies in new buildings laying the groundwork for a common understanding. The methodology involves an integrative review to synthesize relevant research analyzing circular building strategies in existing literature and case study reviews. The analysis revealed five key dimensions for categorizing the diverse strategies found in the publications: concept, level, approach, implementation time, and impact. Based on these findings, a framework has been proposed to help clarify the fundamental characteristics of different circular strategies. Overall, this study contributes to a common understanding of various circular strategies for new buildings. As a practical tool, the categorization framework facilitates the systematic analysis of circular strategies for both researchers and practitioners, enabling the identification of synergies and driving a holistic adoption of CE in the built environment.

1. Introduction

It is well known that the growth of the building stock drives extensive resource consumption and other environmental impacts. In fact, the construction industry is responsible for a significant share of environmental burdens, contributing to ca. 37 % of greenhouse gas (GHG) emissions worldwide with around 10 % of GHG emissions resulting from the production of materials for new buildings [1]. The concept of a Circular Economy (CE) is proposed as one way to mitigate environmental impacts. CE is put into practice through strategies such as reducing, reusing, and recycling that help to narrow, slow, and close resource loops and possibly reduce related environmental impacts [2]. Integrating such circular strategies into new building design becomes essential to address the pressing environmental challenges associated with construction.

While publications on circular strategies for buildings have increased during the last decade [3,4], the understanding of what constitutes a specific strategy is rather disparate and vague. Authors describe similar concepts with varying emphases, contributing to the complexity of this research area. However, despite CE being a prominent subject in building research, there is still no universally accepted definition of CE for the construction sector. Many of the definitions discussed in academic literature are broad and lack a specific focus on the construction industry [5]. A commonly cited reference, Geissdoerfer et al. [2, p. 759], define CE as "*a regenerative system in which resource input and waste, emission, and energy leakage are minimized by slowing, closing, and narrowing material and energy loops. This can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and* *recycling*". Based on this definition there are three main principles regarding the management of material loops in a Circular Economy: "narrowing loops" to improve resource efficiency, "slowing loops" to extend resource availability over time, and "closing loops" to create a circular system where materials are recycled and kept in a circular system [6].

Another commonly discussed framework is based on the so-called R-Strategies. Even though the framework does not have a clear origin [7] authors provided variations with various numbers of R-Strategies over the years [8,9]. Potting et al. [10] present a set of nine R-strategies which are ordered regarding their power to achieve circularity from high to low, where recycling is not seen as part of CE, and their function within a CE: useful application of materials, extending the lifespan of products and their parts, and smarter product manufacturing and use. A selection of "Rs" is also related to the waste hierarchy framework in construction and demolition waste practices and standards [11]. R-strategies are frequently cited in research on circular building strategies, with "recycling" belonging to the most cited R-strategies, even though it often is not considered fully conforming with CE principles [12].

Pomponi and Moncaster [13, p. 711] address the research gap regarding CE implementation on a building level by proposing a research framework for CE in the built environment and define a circular building as "*... a building that is designed, planned, built, operated, maintained, and deconstructed in a manner consistent with CE principles*". Nevertheless, this definition raises questions about which principles are addressed and how they specifically relate to the context of buildings. In contrast to products of other industries, buildings are individual, long-lived, and complex assemblies consisting of a wide range of materials and components with different functions and service lives [13,14]. Hence, it is crucial to comprehend and conceptualize CE within the building industry by considering its complex characteristics to obtain a consistent and systemic implementation [15].

To fill this gap, this paper proposes a categorization framework for circular strategies in new buildings, based on a meta review. The study is guided by the question of how different circular building strategies can be systematically analyzed and categorized. The aim is to promote a framework that enables a common understanding of various circular building strategies, along with a method to reveal synergies and relationships between these strategies. Researchers and practitioners could benefit from a consistent and comprehensive framework for example when benchmarking the environmental performance of different strategies or developing holistic implementations on a building level.

2. Method

This chapter describes both the methodology for analyzing the literature as well as the process behind designing a categorization framework for circular building strategies.

2.1. Integrative review

In this study, literature has been analyzed in form of an integrative review. Integrative literature reviews are commonly applied to synthesize existing literature on a research topic, to create theoretical frameworks and combine different perspectives [16]. This type of review is employed as the goal of the study is to combine different definitions and key concepts into a unified framework, not to gain an extensive overview of all existing literature. The framework aims to serve as a comprehensive representation of existing approaches to analyzing and categorizing various circular strategies applied to new constructions.

After defining the research question, an initial set of literature has been retrieved through Scopus and Google Scholar by searching for "circular strategies for buildings". The search was limited to a time frame of ten years and was conducted in autumn 2023. Additionally, snowballing has been applied to find other relevant publications and include pre-existing work on the concept of CE in the building industry. To address the mentioned research goal effectively and select appropriate literature, the following criteria have been defined:

1. *Analysis or categorization of strategies*: The publication must present, either in words or figures, a way to categorize or group different circular strategies (categorization pattern).
2. *Multiple circular strategies covered*: The publication must have a broader scope and include information on more than one strategy for CE related to buildings. Papers focusing on one single, specific strategy were not considered due to the lack of differentiation.
3. *New buildings addressed*: The publication needs to include circular strategies for new buildings, considering design or material alternations.
4. *Theoretical or practical application*: Strategies can be studied theoretically or through the analysis of case studies

These criteria ensure that the research questions can be addressed fully, without missing important contributions but eliminating irrelevant articles. The articles were screened as a whole, as categorization patterns are often used for working definitions and are therefore not included in title, abstract or core results. The review happened in two steps: in a first thematic analysis, the dimensions for categorization were identified. In a second step, the literature was reviewed regarding their specific way of categorizing the strategies. The focus of this review lies on understanding how existing studies differentiate between circular strategies for new buildings, as a base for developing the framework.

2.2. Framework development
The framework is based on the findings from the literature analysis and was developed in an iterative process. A first scan of the literature revealed five categorization patterns as specified in Section 3. After reviewing the literature regarding the application of those categorization patterns, guiding questions for the framework were formulated which can help to understand and categorize circular strategies for buildings. In focus of the proposed framework are strategies that are introduced by alternating either the design or the material of a structure with regards to CE principles. Immaterial strategies such as documentation, collaboration between different actors in the supply chain, or standardization are not covered.

3. Findings

3.1. Overview: Literature and categorization patterns
After searching, screening, and selecting appropriate literature according to the review methodology in Subsection 2.1, the following eleven articles were included in the analysis.

Table 1: Reviewed articles and identified categorization patterns

Publication	Concept	Level	Approach	Implementation	Impact
Adams et al. [17]				x	
Akhiemen et al. [3]			x	x	
Benachio et al. [5]		x		x	
Çimen [9]	x	x		x	
Eberhardt et al. [15]	x	x			
Fivet and Brutting [18]					x
Gallego-Schmidt et al. [19]	x	x		x	
Geldermans [20]		x			
Nußholz et al. [21]	x	x		x	
Ossio et al. [12]			x		
Rahla et al. [8]		x	x	x	

Table 1 shows the different categorization patterns that were utilized in the articles to categorize and analyze different circular building strategies. The authors discussed these patterns either in text or presented them in figures or tables to categorize the different strategies. The patterns are explained and discussed in the following subsections.

3.2. Concept

Research on circular strategies for buildings is guided by various underlying concepts and principles. Depending on the understanding and definition of CE related to construction, different emphases may arise in the strategies employed. This means that the specific principles and underlying concepts, as defined by different sources (see Introduction), may influence the formulation of strategies and their particular area of focus. In the context of circular strategies for buildings, studies are commonly based on either the principles of handling resource loops or R-strategies.

Gallego-Schmid et al. [19] analyze case studies regarding the different CE principles that they are based on. They differentiate between strategies that either aimed at slowing, narrowing, or closing resource and material loops. Nußholz et al. [21] extend their research from the three mentioned ways of handling material loops to a fourth option “regenerating loops”, which refers to strategies building on renewable materials. This is also in line with the definition of CE from the Ellen MacArthur Foundation (EMF), which is well known for differentiating between technical and biological cycles and emphasizes CE as "*a system where materials never become waste and nature is regenerated*" [22]. Furthermore, Nußholz et al. [21] find that many studies integrated different strategies simultaneously, complicating the ability to understand the correlation between strategies following the principles of narrowing, slowing, closing, and regenerating, and subsequently their potential for decarbonization.

Eberhardt et al. [15] discuss a connection between their research on circular building strategies and eight different R-strategies. They discovered that these strategies were mostly associated with reduce, reuse, and recycle, as these are the most prominent R-strategies within the industry. However, their study does not delve into the detailed connection between R-strategies and specific circular building strategies. It primarily highlights the mention of R-strategies in each reviewed paper [15]. The work by Çimen [9] illustrates a connection to R-Strategies as well.

3.3. Level

As buildings are assemblies composed of many different materials and components, the application of circular strategies can happen on three levels: the building level, the component level (e.g., wall), or the material level (e.g., concrete). Some strategies, like choosing secondary and biobased materials, focus on specific materials. Other strategies operate at a component or system level, such as incorporating reused building components in new structures or designing components specifically for future reuse. Strategies on a building level concern the entire building design, like Design for Adaptability (DfA) or Design for Disassembly (DfD). Strategies on the material level can potentially influence the subsequent design of components (e.g., dimensioning of components based on material choice) and the entire building (e.g., wood vs. concrete structure). Strategies on a building level are often holistic concepts, that rely on a combination of different circular strategies and principles on subsequent levels [21].

Eberhardt et al. [15] conducted a Systematic Literature Review on circular strategies for new buildings, categorizing them by their level of application. The study identified a need for further research, emphasizing the exploration of interactions between different strategies and their combinations to enhance CE effectiveness in the built environment. They emphasize that circularity addresses whole buildings, as well as their components and materials. Moreover, Adams et al. [17] emphasized the need for holistic systems research. In addition, some authors include the industry as a macro-level [5,13]. Geldermans [20] introduces the product as an independent level and proposes a framework concentrating on the difference between product and building level. Strategies on a building level, in their research, include the reuse of existing structures as well as the added value of the intended functions of a building and the integration of adaptable design. They, along with some of the authors like Rahla et al. [8], ground their research not only on the described levels but also on the specific layers of a building, following the layers of Brand [20,23]. This approach involves examining site, structure, skin, services, space, and stuff as distinct systems and exploring their interrelations and connections with each other.

3.4. Approach

The approach relates to the question of how a strategy is realized. It aims to determine whether a strategy is implemented through a modification of the design (e.g., size, volume, form) or an alteration of the material (secondary material, low-impact material, durable material). The response to this question is not explicitly addressed in most of the publications. Some authors choose "material selection" as one distinct category for their discussed circular building strategies, while design-related strategies are found in various other categories.

For instance, Rahla et al. [8] introduce four groups of circular building principles, where three are designated as design strategies (Designing out waste, Design for Adaptability, and Design for Disassembly), and one focuses on material selection. Ossio et al. [12] discuss different "building design approaches" that are associated with the design phase of a building and their connection to different levels and layers. They emphasize that design decisions need to be aligned with material decisions, such as using pure materials in design for disassembly concepts. Moreover, "Design for X" is discussed as a way of labeling design for circularity, such as Design for Circularity (DfC), Design for Disassembly (DfD), Design for Maintenance (DfM), Design for Adaptability (DfA), Design for Recovery (DfR), Design for Change (DfCh), Design for Deconstruction (DfD) and others [12]. Akhimien et al. [3] discuss different circular building strategies clustered as themes (Design for Disassembly, Design for Recycling, building materiality, building construction, building operation, building optimization, and building end of life) with two of the themes addressing specifically design related strategies and one of them concerning materiality.

3.5. Implementation time

The fourth categorization type involves examining the point of implementation throughout a building's life cycle. This point in time seems to depend on factors such as the method of implementation and the different stakeholder's responsibility for the implementation. A building's life cycle as defined in the European standard EN 15978 consists of four phases: material production, construction, use, and end of life [24].

Akhimien et al. [3] present seven classification themes that are connected to the life cycle phases from EN 15978. Rahla et al. [8] propose a *framework for CE implementation throughout the building's life stages* where they categorize different strategies after the life cycle phases stated above. Similarly, Adams et al. [17] conducted a study based on a stakeholder survey, where they presented a table of circular strategies organized after the life cycle phases from EN 15978. It was recognized that the authors associated the implementation of strategies for new buildings, such as DfD or selection of sustainable materials, primarily with the early stages of the life cycle - specifically during design, material production, and construction. In contrast, strategies related to use and end-of-life are often linked to renovation or deconstruction projects. In some studies, the design stage was used for the analysis as a distinct part of the building's life cycle [5,21]. In addition to the design stage, Çimen [9] includes a feasibility and planning stage in their study, preceding both the design phase and the building life cycle.

3.6. Impact

For the environmental evaluation of circular strategies, it becomes imperative to know when a strategy influences the environmental impact of a building. Other than the previous category, this question considers the temporal perspective of the environmental impact associated with the applied strategies, rather than the point of implementation. This differentiation is important in the context of Life Cycle Assessment (LCA) of circular strategies for new buildings. Certain strategies, such as choosing recycled materials, can pay off immediately upon implementation, constituting what is referred to as an upstream impact. Other strategies, like DfD or DfA, pay off in the future and have a downstream impact. The temporal dimension of impact becomes a critical consideration, as other strategies generate environmental benefits over an extended period or a later point in time.

This categorization pattern was discussed in only one of the analyzed articles. The concept of upstream and downstream impacts was mentioned in the context of structural reuse by Fivet and Brutting [18]. Their research describes downstream reuse as the design of new products whose components are meant to be reused in future systems. Upstream reuse on the contrary refers to the reuse of components or materials from existing structures or buildings [18]. This concept has also been adopted in a study by De Wolf et al. [25] who discussed different LCA methodologies for the reuse of building components. Their study highlights the importance of the differentiation between upstream and downstream reuse in the context of LCA.

4. Framework design

Based on the results of the review, five guiding questions were developed that can help to understand and categorize different circular strategies for buildings:

1. *Concept*: What CE principle is a strategy based on?
2. *Level:* On which level is a strategy implemented?
3. *Approach*: How is a strategy implemented?
4. *Implementation time*: When is a strategy implemented?
5. *Impact*: What is a strategy's impact horizon?

Possible answers to these questions are presented as a categorization framework in Figure 1, which can help to analyze specific circular building strategies. By applying the framework to a set of different strategies, synergies and similarities can be explored.

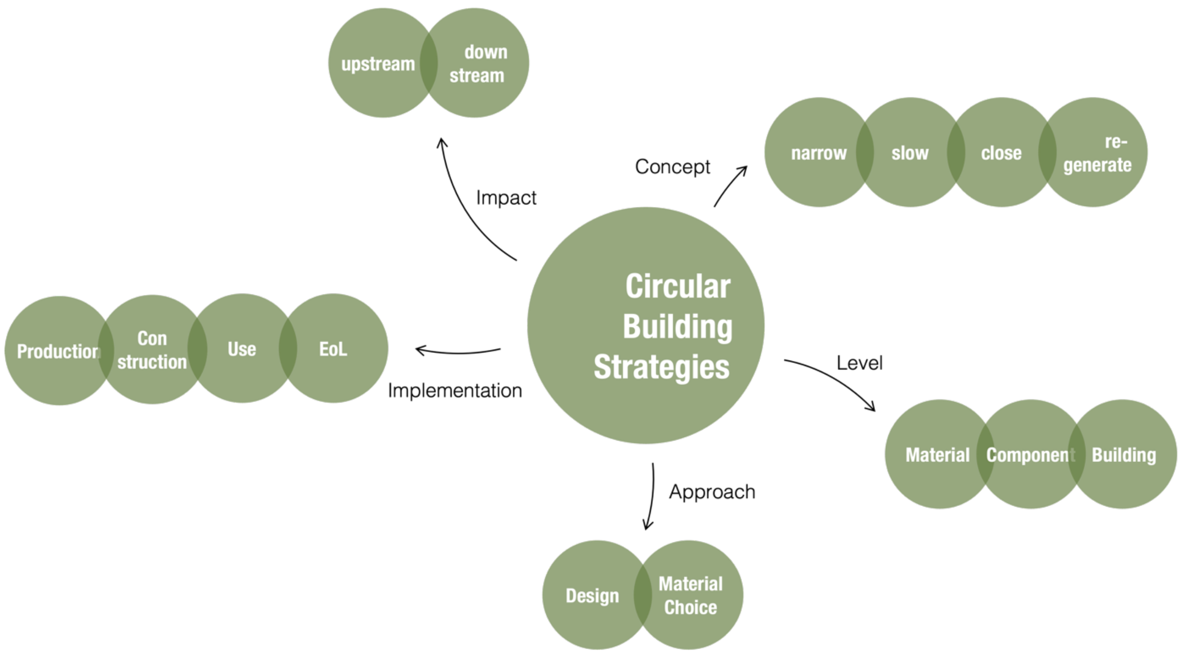

Figure 1 Categorization framework based on categorization patterns from the literature review

Regarding the underlying concept as discussed in Subsection 3.2, the suggested framework incorporates the concept of material loops, emphasizing a collection of general principles rather than exclusively concentrating on more specific R-Strategies. To include both technological and biological aspects, the principle of "regenerating loops" has been included in the framework as well as the three principles of slowing, narrowing, or closing resource and material loops. The question regarding the level of application is answered by the three levels discussed in Section 3.3: material, component, and building, allowing a clear differentiation. When it comes to the question of how circular strategies are implemented, the review has shown a main differentiation between design and material choice, as immaterial strategies have been excluded from the scope of this study. For the point of implementation, the four life cycle phases as suggested by the norm EN 15978 have been adapted. The design phase is not included as a separate phase of the building's life cycle: Even though the decision to change the design of a building, such as DfD or DfA, is made in the planning phase, the implementation of this design happens during a later stage, like the production of the materials or the construction of the building. Regarding the impact of circular strategies, the framework distinguishes between upstream and downstream impacts, adapted from Fivet and Brutting [18] and discussed in Subsection 3.6.

Figure 2 demonstrates the application of the categorization framework, for example, looking at a "*flooring system designed for disassembly*". It is essential to note that the precision of categorization increases with the availability of information about a strategy.

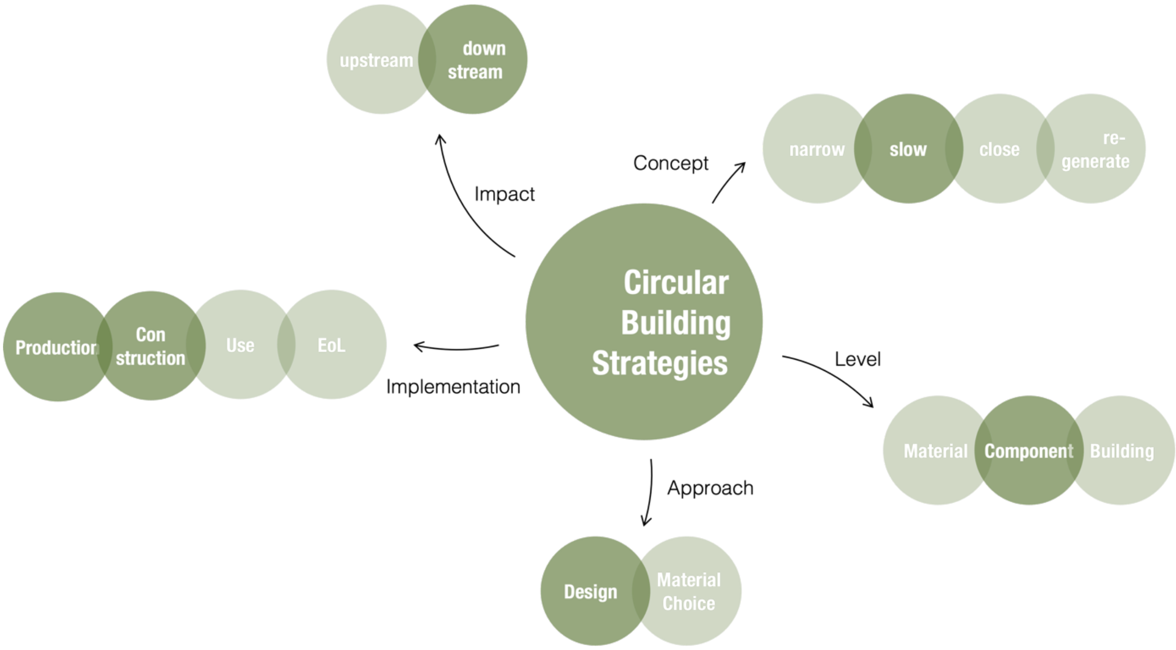

Figure 2 Categorization framework applied to "*flooring system designed for disassembly"*

While certain categorization criteria are clear-cut and allow for straightforward answers, such as whether a strategy applies at a material, component, or building level, others involve interpretation and are more subjective. For instance, determining whether a reusable component contributes to slowing or closing the resource loop can be subjective and depends on the specific application of the strategy. Additionally, categories can align with two or multiple possible answers. As seen in the example, the implementation of the strategy "*flooring system designed for disassembly"* can happen during production when specific building products for disassembly are provided, as well as the construction when these are mounted reversibly. Another theoretical example could be a "*DfD-floor constructed of biobased materials*", which combines design and material choice as an approach. In such cases, it might be helpful to break down the combination strategies into two separate strategies, DfD and biobased materials.

5. Discussion

There is an ongoing need for a more precise and widely accepted definition tailored specifically to the construction sector. In terms of CE principles, the proposed framework includes material loops, reflecting a set of general principles rather than exclusively focusing on more specific R-Strategies. There is limited research investigating the applicability of all R-Strategies to the construction sector and how these R-Strategies can be tailored to better suit the specific needs of the building industry.

Given the focus on strategies for new buildings in this paper, questions about the point of implementation and the temporal aspects of the environmental impact of these strategies gain importance. While the implementation time was discussed in most of the studies, the impact horizon was only analyzed once. However, the construction industry involves products, components, and buildings with significantly longer lifespans compared to those of other industries. Moreover, the horizon for evaluating environmental impact may be even further extended into the future when incorporating CE principles, such as through slowing or closing material loops. A long life span introduces high uncertainties due to evolving requirements and changing ownership during the long building service life. A long-term perspective is crucial when assessing the potential of such strategies to mitigate the environmental impacts and avoid shifting burdens between different phases or circles. Additionally, these temporal considerations are important when evaluating the effectiveness of these strategies in meeting climate targets, such as those outlined in the Paris Agreement.

Looking at the integrity of the framework, it is noteworthy that other analytical patterns, such as the level of readiness (theoretical, experimental, or consolidated) as suggested by Eberhardt et al. [15], were not considered in this framework. This exclusion is intentional, as these patterns may not contribute significantly to the categorization of strategies and are subject to change with advancing research and application. The focus remains on developing a robust and adaptable framework that effectively captures and categorizes circular building strategies for an enhanced understanding of single strategies and their synergies. While the proposed framework covers the most prominent and recurrent categorization patterns found in current research, it is essential to acknowledge that they may not encompass every possible categorization pattern. Other aspects have not been extensively studied and need further investigation to bridge gaps in knowledge and enhance the effectiveness of the framework. The methodology of the paper is recognized to have limitations, including potential biases in the analyzed literature and the subjective nature of categorization.

To enhance the practical application of the framework, it would be beneficial to include examples or case studies illustrating how the framework can be utilized to analyze specific circular building strategies. This could help demonstrate its effectiveness in real-world scenarios and provide guidance for its application by other researchers as well as practitioners.

6. Conclusion

As the volume of research on circular strategies for new buildings grows, the understanding of specific strategies and their interrelations becomes increasingly diverse. Different authors describe similar concepts with varying emphases, contributing to a complex landscape. This article proposes a framework designed to untangle the understanding of different circular strategies for new buildings, providing a structured approach for the analysis of such strategies.

The presented framework is based on five different categorization patterns revealed during the literature review: Concept, Level, Approach, Implementation time, and Impact. The review has been conducted to synthesize existing knowledge and perspectives on circular building strategies. The categorization patterns were used within different research approaches to categorize strategies within the analyzed articles. While the reviewed articles apply only selected categorization patterns for analysis and categorization, this framework covers a combination of five different patterns, facilitating a comprehensive analysis.

Future research could explore the application of such a framework to a wider sample of circular building strategies for new construction to find synergies and relations. Examining synergies and relations of different strategies gains significance, especially when evaluating whole-building concepts that incorporate not just one but several strategies with different focuses and functions. Furthermore, understanding the temporal relationship of these strategies with the building's life cycle, both in terms of implementation and impact time, might be of interest, especially when aiming at calculating environmental impacts without shifting burdens from one phase to another.

References

[1] United Nations Environment Programme 2022 *2022 Global Status Report for Buildings and Construction: Towards a Zero-emission, Efficient and Resilient Buildings and Construction Sector*.
[2] Geissdoerfer M, Savaget P, Bocken N M P and Hultink E J 2017 The Circular Economy – A new sustainability paradigm? *J Clean Prod* **143** 757–68
[3] Akhimien N G, Latif E and Hou S S 2021 Application of circular economy principles in buildings: A systematic review *Journal of Building Engineering* **38** 102041
[4] Hossain M U and Ng S T 2018 Critical consideration of buildings' environmental impact assessment towards adoption of circular economy: An analytical review *J Clean Prod* **205** 763–80
[5] Benachio G L F, Freitas M do C D and Tavares S F 2020 Circular economy in the construction industry: A systematic literature review *J Clean Prod* **260** 121046
[6] Bocken N M P, de Pauw I, Bakker C and van der Grinten B 2016 Product design and business model strategies for a circular economy *Journal of Industrial and Production Engineering* **33** 308–20
[7] Kirchherr J, Reike D and Hekkert M 2017 Conceptualizing the circular economy: An analysis of 114 definitions *Resour Conserv Recycl* **127** 221–32
[8] Rahla K, Mateus R and Bragança L 2021 Implementing Circular Economy Strategies in Buildings—From Theory to Practice *Applied System Innovation* **4** 26
[9] Çimen Ö 2021 Construction and built environment in circular economy: A comprehensive literature review *J Clean Prod* **305** 127180
[10] Potting J, Hekkert M, Worrell E and Hanemaaijer A 2017 *Circular Economy: Measuring Innovation In The Product Chain* (The Hague)
[11] Zhang C, Hu M, Di Maio F, Sprecher B, Yang X and Tukker A 2022 An overview of the waste hierarchy framework for analyzing the circularity in construction and demolition waste management in Europe *Science of The Total Environment* **803** 149892
[12] Ossio F, Salinas C and Hernández H 2023 Circular economy in the built environment: A systematic literature review and definition of the circular construction concept *J Clean Prod* **414** 137738
[13] Pomponi F and Moncaster A 2017 Circular economy for the built environment: A research framework *J Clean Prod* **143** 710–8
[14] Hart J, Adams K, Giesekam J, Tingley D D and Pomponi F 2019 Barriers and drivers in a circular economy: the case of the built environment *Procedia CIRP* **80** 619–24
[15] Eberhardt L C M, Birkved M and Birgisdottir H 2022 Building design and construction strategies for a circular economy *Architectural Engineering and Design Management* **18** 93–113
[16] Snyder H 2019 Literature review as a research methodology: An overview and guidelines *J Bus Res* **104** 333–9
[17] Adams K T, Osmani M, Thorpe T and Thornback J 2017 Circular economy in construction: current awareness, challenges and enablers *Proceedings of the Institution of Civil Engineers - Waste and Resource Management* **170** 15–24
[18] Fivet C and Brutting J 2020 Nothing is lost, nothing is created, everything is reused: structural design for a circular economy *The Structural Engineer* **98** 74–81
[19] Gallego-Schmid A, Chen H-M, Sharmina M and Mendoza J M F 2020 Links between circular economy and climate change mitigation in the built environment *J Clean Prod* **260** 121115

IOP Conf. Series: Earth and Environmental Science **1363** (2024) 012038 doi:10.1088/1755-1315/1363/1/012038

[20] Geldermans R J 2016 Design for Change and Circularity – Accommodating Circular Material & Product Flows in Construction *Energy Procedia* **96** 301–11
[21] Nußholz J, Çetin S, Eberhardt L, De Wolf C and Bocken N 2023 From circular strategies to actions: 65 European circular building cases and their decarbonisation potential *Resources, Conservation & Recycling Advances* **17** 200130
[22] Ellen MacArthur Foundation What is a circular economy? [Online] Available at: https://www.ellenmacarthurfoundation.org/topics/circular-economy-introduction/overview
[23] Brand S 1994 *How buildings learn: what happens after they're built* (Viking)
[24] EN 15978:2011 *Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method*
[25] De Wolf C, Hoxha E and Fivet C 2020 Comparison of environmental assessment methods when reusing building components: A case study *Sustain Cities Soc* **61** 102322