

Review

A Review of Europe's Circular Economy in the Building Sector

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Abstract: This article evaluates Europe's building sector's circular economy (CE). This industry is responsible for 42% of energy consumption, more than 50% of extracted materials, 30% of Europe's water and waste generation, and 35% of greenhouse gas (GHG) emissions. This study focuses on peer-reviewed articles from Scopus and Web of Science databases. Of the first 1750 publications, 2.9% were eligible for a full-text reading and analysis. Most of the trending studies, 92%, promote the circular economy concept through construction materials rather than analyzing the impact of the construction sector on the environment and finding solutions for better implementation, and 41% promote recycling and reuse as the only options. New Design solutions are in 12% of the studies, six-fold more than Law and Legislation, only 2%. Finding an optimal combination of assessing the life cycle of buildings and components and searching for different ways of managing the Construction and Demolition Waste at end-of-life is between 33% and 39%. Ultimately, one evaluated CE proposed frameworks for the building industry based on 10R principles variations. One presents an alternative framework for a circular strategy for the building industry that focuses on Upcycling, replacing the Recover principle.

Keywords: Circular economy; building sector; Europe

1. Introduction

The study's primary purpose is to evaluate the implementation of the circular economy (CE) in the building sector in Europe. The objective is to frame the CE principles, assess the research done in this field, and update the new approaches proposed for better CE integration in the building industry.

Implementing circular economy principles in the building sector is urgent. This industry is one of the world's largest waste generators and consumers of energy and raw materials, and it is taking its toll on the environment [1]. The construction sector is one of the largest harvesters of resources, half of which are non-renewable. Besides, it generates massive waste because it relies on quick and cheap solutions that need to be replaced. At the same time, recycling is still not required on construction sites, resulting in the waste of many valuable materials. In addition, this sector is a relatively high contributor to air pollution caused by land clearing, operation of diesel engines, demolition, burning, and working with toxic materials [2].

The circular economy is a concept that appeared in 1990. It is an environmental change in response to the global need for an ecological economy [9]. The idea gained traction in 2002 with the call for a new industrial revolution where we needed to move from the "cradle to grave" model to the "cradle to cradle" model. The cradle-to-cradle model provides sustainable benefits to society from materials, water, and energy in circular economies and eliminates the concept of waste [3-4].

The Ellen Macarthur Foundation is one of the most critical units advocating the circular economy concept and calling for its implementation. The foundation work is based on research about the benefits of the circular economy and how it can help solve global challenges such as climate change and biodiversity loss [5]. The foundation preset in 2012

the economic and commercial opportunities for the transition to a restorative circular model and the potential for significant benefits across the European Union [6].

In 2015, the European Commission adopted the first circular economy action plan. The goal was to stimulate Europe's transition towards a circular economy, boost global competitiveness, foster sustainable economic growth, and generate new jobs. The work on closing the loop has developed through different strategies and rules of the European Commission, such as the European Green Deal in 2019, to meet the challenge of climate change and environmental degradation. In 2020, the European Commission adopted a new action plan that aims to standardize sustainable products in the European Union, focusing on sectors that use the most resources and where the potential for circularity is high to ensure a minimum of waste to achieve the EU's 2050 climate neutrality target [7].

However, the effective implementation of the circular economy in the building industry is still in its infancy. Comprehensive studies are minimal and primarily focus on construction waste minimization and recycling. That includes framework analyses, system approaches, methodological issues, and aspects or indicators discussed in the state-of-the-art section. This topic will be further discussed in Section 2.

A systematic literature review helps to map out the existing state of the literature in a comprehensive way by evaluating and synthesizing the current knowledge. It helps understand a large body of literature. The present review was carried out in Scopus and Web of Science databases, as detailed in Section 3. Papers were selected for a full reading and analysis, then structured and categorized following their content, and organized according to their relevance to enable the extraction of information. A relevant article is "A review of the circularity gap in the construction industry through scientometric analysis" [8]. It encompasses the construction industry's potential regarding the circular economy and provides an understanding of current research trends and applications. Compared to this work, the authors used the same database and methodology applied worldwide, analyzing 486 papers and using the scientometric technique.

Part of the most critical results demonstrated in Section 4 is that the circular economy is applied as a misplaced buzzword. Despite the increase in research about integrating the circular economy into the building sector's activities these last years, more than 40% are still promoting the first 4 R principles because they are already standardized. Moreover, from most of the selected articles, one verifies that building researchers are unfamiliar with the 10 R principles.

Section 5 elaborates on the contributions and implications of the circular economy implementation in the building sector. The key to optimal circular economy performance is associating its principles with the life cycle of construction materials and buildings. An update for the circular economy principles is proposed in this article that suits the building practices and distinguishes the sector from the other industries, applying efficacious strategies for closing the loop. One offers a new framework adapted to the building sector to assist in implementing the circular economy principles and closing the loop.

2. A common ground and state of the art

2.1. Definition of the circular economy

The principle of circular economy governs nature and circular society. This society enabled humanity centuries before to overcome a scarcity of resources, people, and skills by making the best use of available natural resources, where sharing and reuse were a necessity [9]. However, despite the solid and extensive research on the circular economy, a single, comprehensive definition of the concept is still missing. Moreover, definitions described by science from multiple angles merge the definition with the area, manner, and reason for which it should apply, making it volatile [10].

Each school of thought has a specific definition of the circular economy. Among the most important figures is the Ellen MacArthur Foundation. The circular economy is a restorative or regenerative industrial system by intention and design. A system in which the

concept of "end of life" is oriented towards using renewable energies and aims to eliminate waste by creating materials, products, systems, and business models [11].

The European Commission defined the circular economy as a concept that maintains the value of products and materials for as long as possible; minimizes waste and resources use. To be used again and again and to create added value. And thanks to the circular economy, one can ensure sustainable growth for the European Union (EU), using our resources more smartly and sustainably [12].

Geissdoerfer et al. (2017) state that the circular economy is a regenerative system in which resource input, waste, emission, and energy leakage are minimized by slowing, closing, and narrowing material and energy loops. These results can be achieved through durable design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling" [13].

Several concepts are involved in the circular economy definition. However, there's still conceptual confusion regarding how they relate to or are part of the circular economy. Some are basic, classic, and fundamental principles. Others are more complex, built on the basic ones [10]. To illustrate a comprehensive framework for the circular economy, one should emphasize a combined view of resource scarcity, environmental impact, and economic benefits [14]:

- Resource scarcity in CE: Social prosperity depends on planet earth's finite resource supplies, which makes regenerative use of resources mandatory for CE realization.
- Environmental impact in CE: A society with minimum environmental impacts is a desirable state for nations, governmental bodies, and individuals around the globe.
- Economic benefits in CE: This requires an integrative approach toward business models, product design, supply chain design, and choice of materials which permits each company strives to gain economic benefits to secure profitability and a competitive edge.

Despite the different definitions of the circular economy, its concept characterization brings together researchers from various fields where the circular economy is represented as a closed-loop system. One in which raw materials, components, and products lose value as little as possible, renewable energy sources are used, and systems thinking is at the core [15].

This closed-loop system is a cyclical and restorative model that emphasizes substantial transformations in design, production, consumption, use, waste, and reuse practices. With such a purpose in mind, several frameworks have evolved, beginning with the three Rs: reduce with minimum use of raw materials, reuse with maximum reuse of products and components, and recycle with high-quality reuse of raw materials initiated by the Japanese Government in 2004 [13]. The European Union's waste hierarchy in its 2008 Waste Framework Directive evolved the three Rs into 4 Rs (reduce, reuse, recycle, recover). By 2017, 10 separate Rs contributing to circularity had been identified: Recover, recycle, repurpose, remanufacture, refurbish, repair, reuse, reduce, rethink and refuse, identified as E10RP [11]. While these principles have an indirect effect on lowering the environmental pressure, it is noticed that some researchers had the sole purpose of replacing conventional construction materials with environmentally friendly materials. Notably, lowering carbon dioxide (CO₂) reduces the environmental impact, which is not directly represented by the existing E10RP [16].

E10RP primarily focuses on the existing material and falls in either one of two efforts, "Increasing" or "Decreasing". The principles of Recover, Recycle, Repurpose, Remanufacture, Refurbish, Repair, and Reuse aim to increase the economic value of the existing material after its lifetime has ended or the need has changed. Whereas Reduce, Rethink, and Refuse principles are concerned with decreasing raw material use [16].

Figure 1 represents the 10 Rs principles and their central role in the circular economy implementation. A brief description of these principles can be provided as follows:

- Recover:** Material is incinerated to recover energy;
- Recycle:** Material is processed to obtain new material;
- Repurpose:** Using the discarded product or its parts for a different purpose;
- Remanufacture:** Using abandoned parts for a new product with the same function;
- Refurbish:** Updating or restoring an existing product;
- Repair:** Repairing a product to continue its function;
- Reuse:** Reusing a product discarded but in good condition and fulfils its original function by another user;
- Reduce:** Increasing the efficiency in product manufacture or use by consuming fewer natural resources and materials to make a product;
- Rethink:** Enhancing product usage;
- Refuse:** Removing functions to make products redundant.

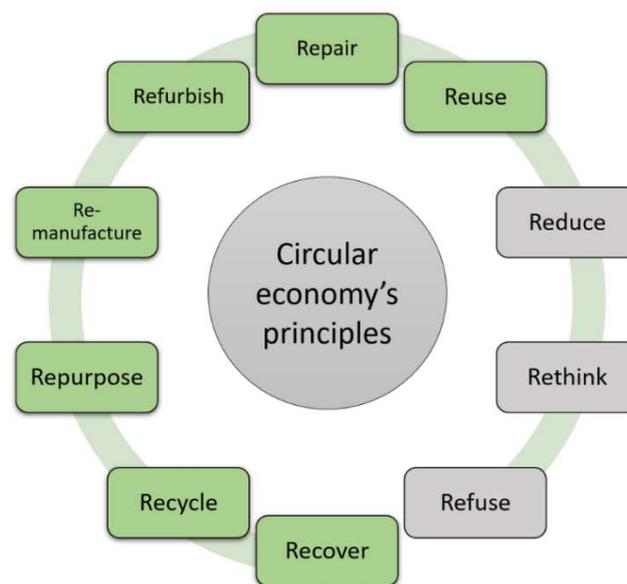


Figure 1. Circular economy's principles

2.2. The circular economy in the building sector

Although the term is relatively new, the circular economy concept is ancient and was present even in prehistory. One of the main principles of the circular economy was applied to the Paleolithic period, which was recycling, where smaller flint tools were made from ancient hand axes [17]. In the Neolithic period, humans reused standing stones to build their graves. Ceramics made from clay and available in abundance were frequently recycled. Old pottery was ground into powder and used in the clay of new pots. In Minoan Crete, this ceramic powder, called grog, was also used to make the mud bricks from which houses were built [17].

The discovery and development of metallurgy mainly characterize the Bronze Age period. Prehistoric people began combining copper and tin to make bronze 2500 before Christ (BC.). It was the primary material of this period, and from the Middle Bronze Age, it was recycled all over Europe. Its design was based on a transformation technology where the object is produced and has to be reproduced [17]. In Hungary, spindle whorls made from fragments of broken pots have been found besides large stones continually reused and repurposed, from millstone to anvil and from the doorway to wall support. At the site of Saruq Al Hadid (now Dubai), research has shown that metalworkers who lived 3,000 years ago in this area used recycling, and copper, bronze, and iron objects found at the site were refashioned from broken ceramic containers to make tools [10].

New archaeological research at the site of Pompeii, the famous city destroyed by the eruption of Mount Vesuvius in Anno Domini (AD) 79, has shown that the ancient Romans recycled their waste and profited from their efforts through artefacts found in ruins. The heaps of garbage found outside the city walls and among the tombs on the outskirts of Pompeii were actually "transit areas" for reusable materials. The waste was regularly sorted and resold for use inside the walls [18]. They were piled up, among other places, along almost the entire outer wall on the city's north side. Some of these mounds were several meters high and included pieces of ceramics and plaster to be reused as building materials [12]. The walls contained discarded tiles, pottery shards, and other repurposed materials that had been coated to create a clean, even surface [18]. The Pompeians lived much closer to their trash than most of us would find acceptable. Not because the city lacked infrastructure and did not care about managing trash, but because society organized waste management systems in urban management around different principles [19].

Regarding the glass, a material known for its renewable formulation, archaeological researchers have proven that in Byzantine times, glass participated in the circular economy cycle [32]. The remelting of glass is a habit dating back to the Late Bronze Age. This technique was used to reuse available or discarded glass objects for various reasons. A similar type of recycling occurred during Late Antiquity and was not limited to glass. The early Christian aversion to pagan art facilitated access to large quantities of unused glass materials that could be reprocessed, such as glass tesserae and window panes. The proto-industrialized Roman economy of the imperial period was based on the intentional collection of broken glass to supply the glass workshops [20].

Ancient Egyptians, Greeks, and Romans applied spontaneous circularity in the construction industry. The workers who constructed the buildings recovered metals from old constructions to reuse them in new ones. In the Middle Ages, there were abundant constructions of churches, cathedrals, and castles. The builders used the materials of the old building to recover all the possible and valuable ones to build new, more imposing constructions, like the Duomo of Pisa built in the 11th century. The ornaments of the latter come from another building constructed before. From this period until the end of the 18th century, artisans reused elements of transformed or deconstructed buildings in other sites. Posters were distributed everywhere around the area to inform of a public sale of the building elements [21].

It was with industrialization that everything changed for society. It was predominantly an agrarian and artisanal society that became commercial and industrial. Industrialization allowed a significant development of the economy in various sectors where production increased thanks to the augmentation in demand for manufactured goods, and this at low cost, where trade and transport of goods over long distances have become more manageable, and where consumers have multiplied. National and international markets have been born. This fact has also led to rural exodus, urbanization, and population growth, thanks to medical advances and better hygiene [22].

The building industry's success is no exception. Construction and building paradigms changed from this ancient circular economy spirit to a modern industry that is currently responsible for 42% of the total EU final energy consumption, more than 50% of extracted materials, 30% of the EU's water consumption and waste generation, and 35% of the greenhouse gases (GHG) emissions. Moreover, the numbers laid bare the scale of the sector's pollution. Construction accounts for 4% of particulate air pollution, more water pollution incidents than any other industry, and thousands of noise complaints annually [2]. These figures result from the environmental burdens that arise at different life cycle phases of buildings, including the extraction of the raw materials for manufacturing the construction materials and products, the construction, operation, and maintenance of facilities, their demolition, and waste management [1].

Regarding the construction sector, almost two decades have passed since the first paper that reviewed the circular economy concept was published in 2004 [23]. The main goal was to evaluate the environmental impact of the development and reconstruction of

the Hai River in Tianjin, Northern China. In this case, the authors introduced circular economy as a new term for innovation and sustainability, and the focus was on ecology development, ecological efficiency, and the project's benefits. The first time one found CE mentioned in Europe was in Germany in 2013. "Reduction of weight and embodied energy in Highrise construction" [24] was the first publication that regarded the circular economy approach, its importance in the construction sector, and its impact on the environment. Since then, the concept and the term Circular Economy have gained traction worldwide and explored, as shown in Section 4.

3. Materials and Methods

3.1. The research sources

To ascertain the trends of current studies related to CE principles and the construction sector and to evaluate the use and integration of the CE principles in the construction sector's studies, one reviewed two different databases, namely Scopus and Web of Science. One chooses these databases to access numerous contents from over 7000 publishers, which are reviewed and selected by an independent Content Selection and Advisory Board (CSAB) to be and continue to be indexed on this tool. These two tools combine a comprehensive and expertly curated database of abstracts and citations with rich data and related scholarly publications in various disciplines.

3.2 The review process

The review process is divided into five steps, starting with one extensive initial search and progressively applying further qualitative criteria. After each screening phase, the screening numbers are registered in Table 1.

Table 1. Review process

	Selection Criteria	Data Base		Total
		Scopus	Web of science	
1	CE in the construction sector in European countries	997	753	1750
2	Articles with keywords about CE principles	166	123	289
3	Articles in English with open access	94	76	170
4	Articles selected after removing duplicated ones			87
5	Articles including the "Recycle" principle			51

1. A set of keywords seen below is applied successively:
Search for "Circular economy" in "Topic", which includes keywords, Abstract, and Title, to obtain all the publications exploring the concept of the circular economy; Added a search for "Construction" to get publications investigating the circular economy in the construction sector; Limited the search to the European countries by using a "by country" filter that includes only the European publications;
2. Add a set of keywords to the research previously made to extract the publications on circular economy principles. The chosen keywords are "Loop", "material flow", "CE principle", "Implementation principle", or "CE strategy". When developing state of art for the circular economy, these keywords were the most used to identify the circular economy principles (the R principles);
3. Only select the publications in English with open access to be able to analyze the content;

4. Duplicates have been disregarded, and screening has been performed for titles, abstracts, and keywords to determine relevant publications concerning the circular economy in the construction sector and its principles' scope;
5. Select the publications that include the recycling principle, as it is the first and primordial principle for a circular economy. For this operation, abstracts of papers are manually reviewed for subject relevancy. Any abstract that did not provide any words, meanings, or sentence structures related to the recycling principle was filtered out.

Despite obtaining 1750 publications concerning the circular economy in the construction sector, only 2.9% of them were eligible for full-text reading and analysis. Most articles are duplicated and do not consider the first circular economy principle, recycling, mandatory in applying the CE conception in all sectors. One presents the results in Section 4.

This article follows the methodology for information collected by the work done in Lieder & Rashid, 2016 [14] and Çimen, 2021 [16]. The combination was the ideal way to select relevant publications and extract critical information.

4. Results

4.1. Publication trend by year

The first Scopus result for the term 'Circular Economy' is for publication in 2001 [25], eleven years after the coining of the word. Figure 2 represents the number of publications treating the concept of circular economy in all sectors per year and the construction sector, starting from 2001 until 2021. As indicated in the graph, there is an exponential increase in the number of publications related to the circular economy, and 2021 marks the year of the highest number, 4829 — only 10% of this involved the building sector.

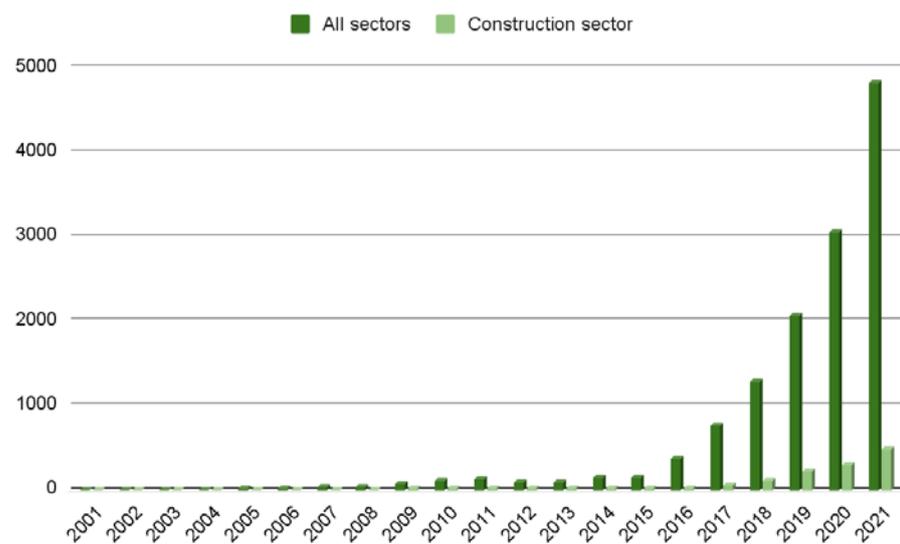


Figure 2. Number of publications per year in all sectors and the construction sector via Scopus

Following the results from Web of Science, one found 14163 publications exploring the circular economy concept — only 9.5% of the total publications were directly related to the building sector. The difference between the results from both databases is 0,5%.

The number of publications has substantially increased since 2016, according to the research made in Scopus and Web of Science, which implies a growing interest from academia in the CE topic from 1 in 2001 to 4830 in 2021. One can explain these results by the significant concerns in translating circular thinking into the building sector to support sustainable development further.

4.2. Publication trend by European country

One analyzed the selected literature according to the first author's affiliation. The analysis indicates the dominance of the European research output in CE. On Scopus, over 63% of the publications were from European countries, whereas Spain, Italy, and the United Kingdom (UK) came in the top three with 14.9%, 13.5%, and 11.5% fractions, respectively. According to Scopus, figure 3 represents the fractions of countries that contributed to these publications.

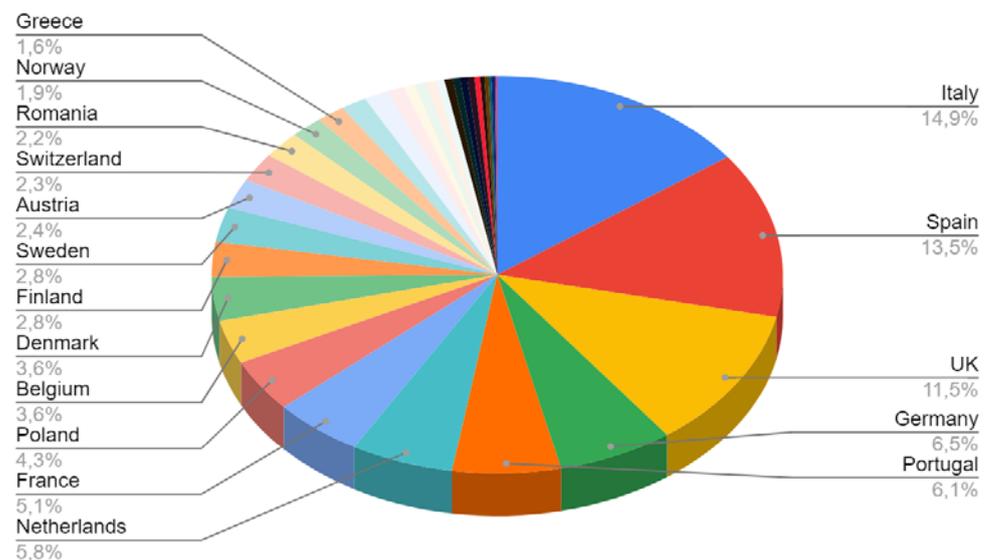


Figure 3. Fraction of CE publications per European country in the construction sector via Scopus

Also, on the Web of Science, European publications represented 55% of the total number of publications. Spain, Italy, and the UK are at the top of the list, respectively, with 12.6%, 12.3%, and 9.5%.

4.3. Publications' subject and area

After obtaining 997 publications in Scopus and 753 in Web of Science exploring the circular economy in the building sector in Europe, as presented in section 3.2, one classified these papers following the specific subject treated, relying on the keywords of each article.

One divided the main 145 common keywords into 13 groups depending on their meaning and common area, as in Table 2. Most studies focus on the promotion of the circular economy and waste recovery. A minority of studies focus on the building sector's environmental impact or the search for solutions for a better implementation of the principles and strategies of the circular economy. For instance, with 330 publications on Scopus, and 249 on Web of Science, only 33% of the papers combined treated the basic first

circular economy principles (Recycle, Reuse, Reduce). None of the seven rest of the R principles was listed as a keyword in these publications. Only 12% of the articles cover Design, despite its contribution and importance in integrating circular economy practices into a building's life stages. Merely 6% of the studies mention Water Pollution, and Laws and Legislation are the less attractive field, with less than 2%, although the importance of this sector in promoting and enforcing new methodologies.

Table 2. Main used Keywords groups in the publications

Circular economy + Keywords group	Number of Keywords /group	Number of publications / group		total publications /group	Fraction of use /group
		Scopus	Web of Science		
Construction materials	35	919	693	1 612	92%
Construction sector	14	730	551	1 281	73%
Waste	15	651	492	1 143	65%
sustainability	6	502	379	881	50%
Industry's economy	15	508	384	892	51%
Life Cycle Assessment	5	384	290	674	39%
Environment	11	348	263	611	35%
3R principles	4	330	249	579	33%
Construction impact	11	289	218	507	29%
Materials proprieties	6	167	126	293	17%
Energy	5	132	100	232	13%
Design	5	121	91	212	12%
Resources	5	101	76	177	10%
Water	3	58	44	102	6%
Building Information Modelling	2	41	31	72	4%
End of Life	1	19	14	33	2%
Laws and legislations	1	17	13	30	2%

4.4 Selected publications for the discussion

At the end of the screening and the selection, obtained papers are studied in a full review to analyze their content, findings, contribution, subject, stage, and scale under the scope of the CE principles to be used for the discussion.

Table 3 summarizes the relevant papers in alphabetic order, indicating the R principles taken into consideration, besides the main ideas explored in each publication.

Table 3. Content analysis of the selected publications

Ref	CE principles					LCA	Waste/ CDW	EoL	Design/ DfD	BIM
	Recycle	Reuse	Reduce	Recover	> 4 Rs					
26	+					+				
27	+					+				
28	+					+				
29	+					+				
30	+					+	+			
31	+									+
32	+					+				
33	+						+			
34	+						+		+	
35	+	+					+		+	
36	+	+				+				+
37	+	+					+			
38	+	+						+		
39	+	+		+		+				
40	+	+	+	+	+		+			
41	+	+	+	+	+	+			+	
42	+	+	+	+	+	+				
43	+	+	+	+			+			
44	+	+	+	+	+				+	
45	+								+	
46	+								+	
47	+	+				+				
48	+	+	+	+	+	+	+	+	+	+
49	+	+							+	
50	+	+	+	+	+					
51	+	+	+				+	+		
52	+	+	+	+			+	+		
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57	+		+	+		+	+	+		
58	+	+		+						
59	+	+	+	+			+			
60	+	+	+	+	+		+	+		
61	+	+					+			
62	+	+						+		
63										
64	+		+	+			+	+		
65	+					+	+			

Ref	CE principles					LCA	Waste/ CDW	EoL	Design/ DfD	BIM
	Recycle	Reuse	Reduce	Recover	> 4 Rs					
66	+	+	+	+	+				+	
67	+	+	+	+			+			+
68	+	+	+	+	+	+	+	+	+	
69	+	+		+		+	+	+	+	+
70	+	+					+			
71	+	+		+		+	+			
72	+		+	+			+	+		
73	+	+		+		+				
74	+	+	+	+	+				+	
75	+	+	+	+			+	+	+	
76	+	+	+						+	

4.5. Content analysis

Table 3 presents different subjects that one analyzed in the selected papers. The most targeted ones were: Life cycle Assessment (LCA), Construction and Demolition Waste (CDW), End of Life (EoL), Design for Disassembly, and (DfD) Building Information Modelling (BIM). Figure 4 indicates the number of publications associated with each studied subject.

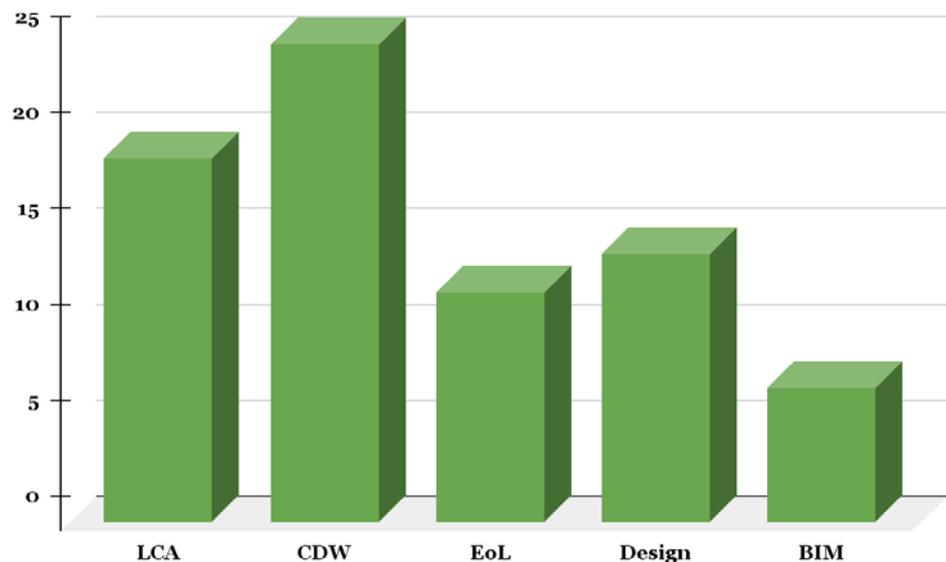


Figure 4. The diagram of the publications' area

According to figure 4, CDW is the most studied subject, with 49% of the interest of the publication focused on the waste generated from the construction, renovation, repair, and demolition of houses, building structures, roads, bridges, piers, and dams. The papers investigating the LCA represent 37% of the total. The authors used the LCA technique to

evaluate the potential environmental impacts of products, materials, or buildings throughout their different stages of the life cycle (Production stage, construction stage, use stage, and the end-of-life stage), proposing new assessment methodologies. The Design shows as a life stage, a technique, or an approach in 27% of the publications. The DfD was the most proposed approach by authors, emphasizing the importance of managing the architectural parts for a future design of structures that can be separated and reconstructed using the same materials to a large extent. A set of 23% of papers focuses on the EoL stage, stressing the importance of the last life cycle stage, calling for replacing it with a system of reduction, alternative reuse, recycling, and recovery of materials in the production/distribution and consumption processes. And despite its performance in presenting a built asset containing information about the building's geometry, material properties, and quantities of elements, BIM received minor importance, with less than 14% of the papers investigating the subject.

Despite the facilitation and performance of LCA, CDW, EoL, DfD and BIM in implementing the CE strategies in the construction sector, they were only considered in 6% of the selected publications.

As demonstrated in figure 5, these publications worked on finding an optimal combination of assessing the life cycle of buildings and components by searching for different ways of managing the CDW at the end-of-life stage. Furthermore, proposing ideas to design for disassembly and assembly of the construction to extend their lifespan and use BIM performance in collecting buildings' materials and component data to facilitate the process.

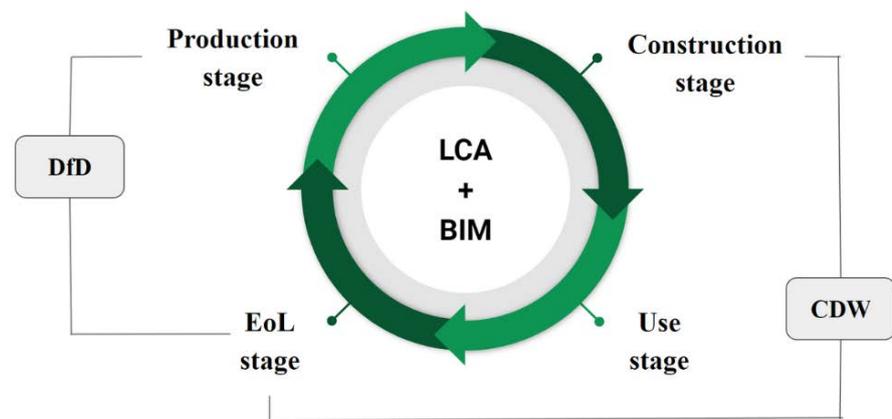


Figure 5. The link between LCA, CDW, EoL, BIM, and DfD

However, 41% of the publications did not apply the CE principles and only enlisted recycling and reusing as traditional practices to be performed by the industry. These papers investigate only a specific subject related to the circular economy without concerns about its principles.

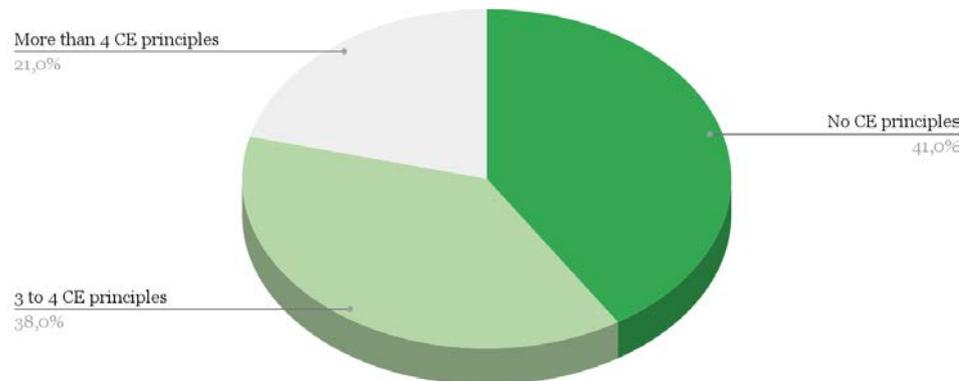


Figure 6. Selected publications fractions according to the CE principles number

As shown in figure 6, 38% of the selected publications considered the 3R basic principles (Recycle, Reuse, Reduce). And 64% of the publications that analyzed the CDW subject are included in this fraction. Nevertheless, 21% of the publications had investigated more than 4 CE principles, and table 4 marks the involved papers with their assigned principles.

Table 4. CE principles scales for the papers with more than 4R principles

		The CE principles											
		R's N°	1	2	3	4	5	6	7	8	9	10	11
Articles number according to table 3	42												
	53												
	68												
	41												
	40												
	50												
	44												
	66												
	74												
	48												
	60												

For simplicity, Table 3 identifies the papers by their number and filters by the number of CE principles each publication considered. Scaled from 1 to 11 associated to Recycle, Reuse, Reduce, Recover, Repair, Refurbish, Remanufacture, Repurpose, Refuse, Rethink and Replace. The results are in table 4.

In addition to the basic 4 R principles (Recycle, Reuse, Reduce, Recover), 100% of the publications indicated in table 4 considered the principle of "Repair" as the easiest and most traditional way to extend the lifespan of a component or element. "Refurbish", "Remanufacture", and "Repurpose" are also principles applied to develop the use stage in the

life cycle of a building. These principles are in 63% of the papers, which included more than 4 of the CE principles. A consequence of their potential to increase the value of materials and prolong the buildings' lifespan.

To decrease the use of raw materials, "Refuse" is a common practice considered in 45% of the last selected papers. According to table 4, 21% of these publications analyzed the 10 CE principles, representing 6% of the total. As previously indicated, 37% of the selected papers considered the LCA approach in their analysis. 36% implemented the circular economy principles in the life cycle of components and buildings, and 43% of these papers match the publications that implemented all the 10 R principles.

One of these papers, titled "Construction and built environment in the circular economy: A comprehensive literature review" [16], proposed a new principle for the circular economy, "Replace". This principle mainly concerns introducing a new and more sustainable material, alternative design or manufactured elements to replace existing materials.

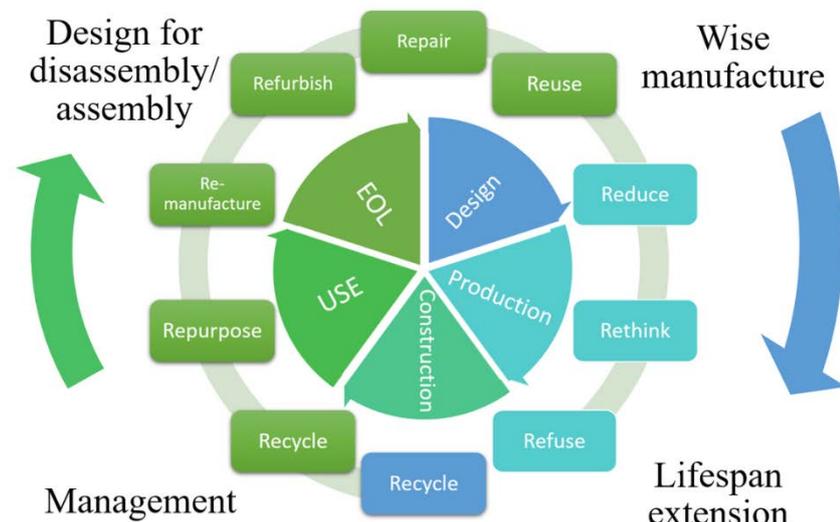


Figure 7. The new framework for circular economy in the building sector

5. Discussion

As presented in subsection 4.5, only 2.9% of the publications concerning the circular economy in the building sector in Europe were eligible for a full investigation, as the rest of the publications were whether not discuss the basic and first principle of the circular economy; Recycle, or not linked to the CE implementation in the construction sector.

38% of the selected publications considered the 3R and 4R principles with concerns about the CDW and trying to decrease the extraction and use of raw materials. At this level, it is hard to close the loop as the "Recover" principle, where heat, electricity, or fuel are retrieved from non-recyclable materials by incineration. One may question the merit of such a solution, especially in the construction sector, where the building's components are composite materials that are not bio-waste. Their incineration tends to produce hazardous air pollutants.

As previously confirmed, in 41% of the selected studies, the R principles were not examined; instead, these articles only cite Recycle and Reuse as rules of the traditional practices for sustainability. The words "Recycle" and "Reuse" were used to promote the

circular economy without practically associating them with implementing CE in the construction sector as an integral part of the concept's strategy. Whether it is about the LCA model and cost evaluation or design proposal for passive buildings or waste management, the recycle and reuse terms were cited in these papers with no awareness of their meaning or role in the circular economy's loop. Despite the Circular Economy term remaining in the article.

5.1. Implementing the CE principles into the life cycle of buildings and their materials

Only 21% of the studies were about implementing the CE principles, figure 8, and the most relevant studies represent 6% of the selected papers. The 10 R principles were examined and implemented in buildings and component life cycles.

Only one article, "Selection Criteria for Building Materials and Components in Line with the Circular Economy Principles in the Built Environment-A Review of Current Trends" [68], included the 10 CE principles, besides the LCA, CDW, EoL, DfD, and BIM, the catalysts of the CE implementation in the construction sector. The authors propose a new practice of "the circular building" that embeds every aspect of the circular economy concept. One designs the building steps, planning, building, operating, maintaining, and deconstructing in a manner consistent with CE principles. It has a closed life cycle system wherein components and materials are optimally used and retained at their highest value.

In conclusion to the work of [36], [41], and [53], one can associate each CE principle with its function in the different life cycle stages of a circular building using three main strategies to increase circularity.

The first strategy is to manufacture circular products for the first life cycle stage (Production stage) and the last life cycle stage (end-of-life stage). This strategy includes the Refuse, Rethink and, Reduce principles.

The second strategy is to extend the lifespan of the building's components, which can be associated with the use stage. This strategy includes the Reuse, Repair, Refurbish, Remanufacture, and Repurpose principles.

The third strategy is associated with the last life cycle stage, which is to manage the end-of-life of a building. This strategy includes the Recycle principle.

Some authors associate the Recover principle with the third strategy: heat, electricity, or fuel are retrieved from non-recyclable materials by incineration [41], [53]. In one's opinion, this principle may reduce the introduction of new raw materials and mitigate waste volume. However, the incineration of the disposed of materials will take the strategy steps away from circularity. From an environmental point of view, this operation is polluting and a source of dioxin emissions even in its most modern versions, with the disadvantage of accompanying toxic ashes production.

One can also challenge the new proposal of the Replace principle. This idea distinguished itself and went beyond the others investigated in the 10 R principles [16]. It founds on creating new materials or components to use in future building projects by lowering the level of CO₂ compared to the existing material. However, it fails to respect the CE's fundamental goals of increasing the construction material's economic value or decreasing raw material usage and extraction.

5.2. Design strategy

As mentioned before, 27% of the selected publications investigated the design process and proposed multiple techniques to design for circularity, and the DfD was the most used approach for circular buildings.

As noticed in the article [53], one of the most crucial parameters in DfD is the choice of construction technology and how one will assemble and disassemble the building ele-

ments. Materials should be eligible for embracing CE principles such as reuse, refurbishing, repair, and higher purity to limit quality loss during the assembly/ disassembly process.

On the other side, several studies have proposed integrating Materials Passports into Building Information Management, allowing building stakeholders to track materials, understand their origins, and assess their quality.

In [48], the author proposed a Disassembly and Deconstruction Analytics System (DDAS), a system architecture that BIM software developers could use to incorporate building deconstruction and materials recovery functionalities into BIM software for the construction industry. This feature will enable architects and design engineers to evaluate building designs for end-of-life sustainability performance from the design stage.

As concluded in [52], to support waste minimization throughout building design stages, Architects should use BIM to simulate the most effective construction mode and the most sustainable project configuration in the CE framework. This possibility emphasizes the need for a comprehensive investigation to explore the potential of BIM to reduce construction waste in building design. This novel approach can bring about CE by increasing collaboration between stakeholders and allowing them to track materials, understand their origins, assess their quality, and evaluate building designs for end-of-life sustainability performance.

In the recent past, architects and engineers designed and constructed existing buildings for demolition. They did not prepare for deconstruction. The DfD approach cannot be applied. One should also include the merge of CE principles and the concept of reusing their assets after their end-of-life to achieve higher levels of environmental performance with less material input and more material reuse, repair, refurbishing, and recycling at their end-of-life.

One concludes from the analysis of the selected papers that the focus is on the new building construction instead of the design of the existing building for demolition. The design for demolition will require developing deconstruction building techniques at their end of life for ulterior assembly into new structures or components. The alternative is the current praxis: demolishing and losing a substantial amount of materials, increasing pollution production and generating more waste.

5.3. Upcycling for a CE principle

Upcycling emerges as a practice of creatively reusing the buildings' elements and is considered high-level recycling in the circular economy trend.

Integrating upcycling methodology into the design process permits the materials to regain value instead of turning into waste by reusing as much as possible and by creating new materials and components from old or used ones or from waste generated at the end-of-life of the building itself [46]. It addresses the existing architectural stock and its future use, not as a whole but as separate upcycled modules.

One should consider the replacement of the Recover principle from the CE principles with upcycling. Recover restricts the closing of the loop process at 100% and carries harmful impact on the environment. Upcycling in the building industry is a new practice integrated into the CE principles to discard as few architectural components as possible and reduce or even eliminate waste. One can apply this method to buildings that were constructed without any prior consideration for this practice, as all basic building materials have the potential to be reused, as projects typically consist of brick, concrete, metal, and wood.

6. Conclusions

A close look at the published activity in the construction sector regarding circular economy reveals that this issue is still in its infancy, corresponding to 10% of the research

about CE in Europe. Undoubtedly, researchers try to bend to the Circular Economy principles by adapting their research to some aspects of CE. However, the results show that the efforts to approach this concept are insufficient. Researchers and stakeholders are missing the point of the CE implementation in the building sector by ignoring the critical aspects of the CE: reducing the consumption of resources and waste production; retaining the value of resources as long as possible within the system. Future solutions may rely on particular strategies as a combination between the R principles and the buildings and materials' life cycle evaluation.

Most of the trending studies, 92%, are dedicated to promoting the circular economy concept through construction materials rather than analyzing the impact of the construction sector on the environment and finding solutions for better implementation. Only 33% of the papers treated the basic first circular economy principles, but this seems significant compared to the design area that is only considered in 12% of the studies, or worst, compared to the law and legislation subject that was only present in 2% of them. Furthermore, a significant part of the studies, 41%, is still promoting recycling and reuse as traditional practices that should be performed in the construction sector, presenting it as a step towards a circular economy without concerns about its principles.

Life cycle assessment (LCA), Construction and Demolition Waste (CDW), End of Life (EoL), Design for Disassembly, and (DfD) Building Information Modelling (BIM) are performance parameters that facilitate the implementation of the CE strategies in the construction sector. Between 33% and 39% of the studies have focused on finding an optimal combination of assessing the life cycle of buildings and components and searching for different ways of managing the CDW at the end-of-life stage. These studies also proposed ideas to design for disassembly and assembly of the construction to extend their lifespan and use BIM performance in collecting buildings' materials and component data to facilitate the process.

However, the review also demonstrated that less interest is given to the existing buildings and the inclusion of upcycling as a new practice for the design strategy to discard as few architectural components as possible, eliminate waste, and close the loop at 100%. One found that this issue is only 2% of the occurrences. The detailed note is that the design for demolition should be replaced by a technique to deconstruct buildings at their end of life for ulterior assembly. The inclusion of incineration in the "Recover" principle is still practiced for retrieving energy at the end of using materials that become waste. The "Recover" principle should be eliminated from the CE principles to guarantee to close the loop without hazardous emissions.

BIM could be explored to further for several strategies to foster CE in the to foment:

- Processes for wise manufacture of materials for durability associated with Refuse, Rethink and Reduce principles;
- Procedures for extending the lifespan of buildings and their components by repairing, refurbishing, remanufacturing, and repurposing new and existing materials;
- Design for the buildings' disassembly and ulterior assembly for the buildings' end-of-life.

Implementing an integrated approach allows building stakeholders to track materials, understand their origins, and assess their quality. It will enable architects and design engineers to evaluate building designs for end-of-life sustainability and support waste minimization throughout the building design phases.

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