Assessment of Europe’s circular economy in the construction sector

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Abstract

The research is dedicated to the evaluation of the implementation level of the circular economy in the construction sector in Europe.

The circular economy (CE) has received increasing attention in the last decade. However, only 10% of the studies concern the construction sector, where the concept implementation is still at its begging and treated as a trend for environmental practices.

Integrating the CE principles in the construction sector urge as the sectors' practices are harmful to the environment, being responsible for 42% of total Europe's energy consumption, more than 50% of extracted materials, 30% of Europe's water consumption, and waste generation, and 35% of the greenhouse gases (GHG) emissions.

The research holds the assessment of the studies done about the CE and its principles in the construction sector, carried out in a review using namely Scopus and Web of Science as databases. Of 1750 publications, only 2.9% were eligible for a full-text reading and analysis. The goal is to extract the relevant information and to deduce an optimal solution to implement the circular economy principles into the life cycle of buildings and construction materials.

A great part of the studies, 41%, is still promoting the recycle and reuse as traditional practices that should be performed in the construction sector. One concluded that the "Recover" principle should be eliminated from the CE principles as its practice harms the environment.

One discovered that the key to optimal CE implementation in the construction sector is to combine the CE principles with the life cycle of materials and buildings.

One proposed a new circular economy framework adequate for the construction sector activities, where the principles of the concept are optimized and adapted to all the life stages of construction and circular strategies are suggested for closing the loop by applying sustainable manufacturing, lifespan extension, waste management, and design for assembly and disassembly.

Furthermore, one suggested "upcycling" as a new practice for the design strategy, with the aim of discarding as few architectural components as possible, eliminating waste, and especially, closing the loop at 100%.

Resumo

A investigação é dedicada à avaliação do nível de implementação da economia circular no sector da construção na Europa.

A economia circular (CE) tem recebido uma atenção crescente na última década. No entanto, apenas 10% dos estudos dizem respeito ao sector da construção, onde a implementação do conceito está ainda em fase de imploração e é tratada como uma tendência para as práticas ambientais.

A integração dos princípios da CE no sector da construção, uma vez que as práticas dos sectores são prejudiciais para o ambiente, sendo responsáveis por 42% do consumo total de energia da Europa, mais de 50% dos materiais extraídos, 30% do consumo de água e geração de resíduos da Europa, e 35% das emissões de gases com efeito de estufa (GEE).

A investigação realiza a avaliação dos estudos realizados sobre a CE e os seus princípios no sector da construção, realizados numa revisão utilizando nomeadamente Scopus e Web of Science como bases de dados. A partir de 1750 publicações, apenas 2,9% foram elegíveis para uma leitura e análise de texto integral. O objectivo é extrair a informação relevante e deduzir uma solução óptima para implementar os princípios da economia circular no ciclo de vida dos edifícios e materiais de construção.

Uma grande parte dos estudos, 41%, ainda está a promover a reciclagem e reutilização como práticas tradicionais que devem ser realizadas no sector da construção. Concluiu-se que o princípio "Recuperar" deve ser eliminado dos princípios da CE, uma vez que a sua prática prejudica o ambiente.

Descobriu-se que a chave para uma implementação óptima da CE no sector da construção é combinar os princípios da CE com o ciclo de vida dos materiais e dos edifícios.

Um propôs um novo estrutura de economia circular adequado às actividades do sector da construção, onde os princípios do conceito são optimizados e adaptados a todas as fases de vida da construção e são sugeridas estratégias circulares para fechar o ciclo de vida aplicando o fabrico sustentável, extensão da vida útil, gestão de resíduos, e concepção para montagem e desmontagem.

Além disso, sugere-se a "reciclagem" como uma nova prática para a estratégia de concepção, com o objectivo de descartar o menor número possível de componentes arquitectónicos, eliminando os resíduos e, especialmente, fechando o laço a 100%.

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1. Introduction

The main purpose of the study is to evaluate the implementation of the circular economy (CE) in the construction 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 industry.

The implementation of the circular economy principles in the construction sector urge as this industry is one of the world's largest waste generators and consumers of energy and raw materials, and it's taking its toll on the environment.

For instance, the construction sector is one of the biggest harvesters of resources, half of which are non-renewable. Besides, it generates a massive amount of waste because it relies on quick and cheap solutions that need to be replaced. At the same time, recycling is still not a requirement 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.

Effective implementation of the circular economy in the construction industry is still in its infancy stage, as comprehensive studies including the system approach, methodological issues, aspects and indicators, and frameworks are very limited and mostly focus on construction waste minimization and recycling.

To map out the existing state of the literature in a comprehensive way, a systematic literature review is conducted by evaluating, and synthesizing the existing knowledge. It helps understand a large body of literature.

The review was carried out in two different databases, namely Scopus and Web of Science. Papers were selected for a full reading and analysis, then, structured and classified following their content, and finally, organized according to their relevance to enable the extraction of information.

The key to optimal implementation of the circular economy is to associate its principles with the life cycle of construction materials and buildings. An update for the circular economy principles is proposed in this research that suits the construction practices and distinguishes the sector from the other industries, applying efficacious strategies for closing the loop. For that matter, a new framework adapted to the construction sector is proposed to help implement the circular economy principles and to close the loop.

Despite the increase in the number of research made about integrating the circular economy into the construction sector's activities these last years, more than 40% of them are still promoting the first 4R principles as they are standardized and not yet familiar with the 10 R principles.

The present study is structured as follows. The first chapter is the introduction of this thesis, the second Chapter presents the theoretical background and the state-of-the-art of circular economy. The third chapter displays the materials and methods used for the data analysis. The fourth chapter demonstrates the results obtained throughout the evaluation and maps the outcomes. Finally, the fifth part elaborates on the contributions and implications of the research regarding the implementation of the circular economy in the construction sector.

2. Theoretical background and state of the art

2.1. Definition of the circular economy:

2.1.1. Divers definition:

The principle of circular economy governs nature and circular society, a society that 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 [1].

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 tend to merge the definition itself with the area, manner, and reason for which it should apply, making it volatile [2].

Each school of thought has a specific definition of the circular economy. Among the most important figures is that of the Ellen MacArthur Foundation, where the circular economy is defined as a restorative or regenerative industrial system by intention and design. A system that replaces the concept of "end of life", which is oriented toward the use of renewable energies and aims to eliminate waste through the design of materials, products, systems, and business models [3].

The European Commission, in its 2015 EU Action Plan for the Circular Economy, 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, and keep the material within the economy when a product has reached the end of its life, to be used again and again and to create further value. Thanks to the circular economy, we can ensure sustainable growth for the EU, using our resources in a smarter and more sustainable way [4].

According to Geissdoerfer et al. (2017), the circular economy is 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" [5].

On the other hand, the Circular Academy approaches the concept of circular economy based on a transformative economy with production and consumption patterns, inspired by the principles of ecosystems and restorative design, which increases resilience, eliminates waste, and creates shared value through increased circulation of material and immaterial flows [6].

There are several concepts involved in the circular economy definition, but 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 [2].

2.1.2. Goals and benefits of the circular economy:

To illustrate a comprehensive framework for the circular economy, we should emphasize a combined view of resource scarcity, environmental impact, and economic benefits.

Economic benefits in CE: This requires an integrative approach toward business models, product design, supply chain design, and choice of materials which permits each individual company strives to gain economic benefits in order to secure profitability and a competitive edge.

Resource scarcity in CE: Social prosperity depends on planet earth's finite resource supplies, which makes regenerative use of resources mandatory for CE realization. The underlying factors in this context concern circularity of resources, material criticality, and volatility of resources in the light of the globally increasing number of industrial activities.

Environmental impact in CE: A society with minimum environmental impacts is a desirable state for nations, governmental bodies, and individuals around the globe [7].

According to the European Commission, the circular economy model can create secure jobs in Europe, promote innovations that give a competitive advantage and provide a level of protection for people and the environment. It can also provide consumers with more durable and innovative products that provide financial savings and a better quality of life [4].

In the face of these challenges, a call is up for solutions inspired by nature, with the goal of using more efficiently our resources while at the same time reducing the negative impact on the environment [8].

2.2. History of the circular economy:

The circular economy is a modern concept that appeared in 1990 in the book “Economics of Natural resources and the environment” by D. Pearce and R. Turner, where he defined it as a model of production and consumption that involves essentially reducing, reusing, and recycling existing materials and products as long as possible. It is an environmental change in response to the global need for an ecological economy [9].

Although the term is relatively new, the circular economy concept is ancient and was applied in several sectors until the middle of the 20th century. We find this spontaneous circularity in the 17th century when the profession of rag pickers was born. They are the first "recyclers". The poor collect old clothes, rags, animal bones, and all kinds of items to be reused. They boiled the bones for fat to make candles. They turned the cloth and rags into paper, and the farmers used the sludge to fertilize their fields. Many people survive by collecting and recycling waste [10].

It was with industrialization that everything changed for society. It was predominantly an agrarian and artisanal society that became a commercial and industrial one and this was thanks to a series of industrial revolutions that started in Great Britain in the middle of the 18th century with the invention of steam engines, and spread to Western Europe from 1820 when France returned with the generalization of looms and the construction of the first railway lines. Around 1870, Germany, Canada, and the United States joined France and the United Kingdom, succeeded by Russia and Japan in 1890 [11].

An industrial advance was achieved thanks to three fundamental elements, which are Coal, a hegemonic source of energy, iron, the primary material and the steam engine, a universal engine, whether in the field of textiles or in the railway sector, a vital sector of the industry since it has been able to expand markets by exposing regional industries to competition and by stimulating the dynamics of innovation in the creation of tracks, stations, bridges. This advance called for the gradual emergence of new energy sources such as electricity and petroleum and new materials derived from iron, such as special steel and aluminum. The development of inorganic chemistry also characterized this period by discovering the bleaching properties of chlorine, the manufacture of artificial soda, and the discovery of sulfuric acid. Agriculture was also modernized, especially with the discovery of artificial fertilizers [11].

Resulting from these revolutions, 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, where consumers have multiplied and national and international markets have been born. This fact has also led to rural exodus and urbanization, and population growth thanks to advances in medicine and better hygiene.
This approach, based on the "take-make-dispose" model where resources and production are considered unlimited, involves collecting raw materials for their transformation into finished products and their distribution to the customer until such time. Value is created in this economic system by producing and selling as many products as possible [12].

Although it was an outstanding period in history during which several technical innovations appeared that had a significant impact on the economy, social classes, and urbanization, over time, the linear economy harmed the environment and has become unsustainable, presenting various problems with severe consequences, including the wastefulness which became, after 1945, a manifestation of freedom and a sign of abundance, while recycling brings back bad memories of the war [13].

While products were generally manufactured to meet specific and localized needs, their industrial production for a more global market contributes to increased wastefulness. The remains become less attractive as the purchasing power of the population increases. As the manufactured products become composite, that is to say, less degradable and difficult to reuse for other uses without complex transformation, many products come to market in large shipments, and not all products are sold [14]. This leads to excess inventory, on which the company will lose money, and overproduction means more waste.

In addition, the development of different economic sectors and the acceleration of their activity have caused a significant emission of carbon dioxide into the atmosphere, such as the consumption of energy for the extraction of fossil fuels or the production of electricity, the production of methane for fermentation, or even the production of cement for buildings.
On the other hand, the overexploitation of natural resources, and the depletion of raw materials such as minerals and fossil fuels, endanger biodiversity. From 1970 until today, the extraction of natural resources has almost quadrupled. One of the fundamental problems is that there will be less and less of these collected resources, which will be circularized, so more and more resources will either be lost as waste or pollution or stored in warehouses.

Therefore, we can conclude that this linear production-consumption model is not part of the logic of sustainable development and must give way to another alternative that will protect the environment and its resources.

This is where we started to reintegrate spontaneous circularity with improvement and control of its bases for a better adaptation. The first introduction to the principles of the circular economy was made by the economist Boulding in his book 'The Economics of the Coming Spaceship Earth' written in 1966. He philosophically explains the difference between an open system and a closed system. An open system is maintained in the middle of a passage of inputs and outputs. A closed system is where the outputs of all its parts are linked to the inputs of other parts. In this circular system, the flow of inputs and outputs, whether they are energy, matter, or information, is by no means a desideratum and should be seen as something to be minimized rather than maximized [15].

On the other hand, Spilhaus appeals, in his article 'Resourceful Waste Management' published in 1996 to the recovery of waste, and it should be considered as a resource and the possible basis of huge new industries dedicated to the reuse of waste residues [16].

Architect Walter Stahel explained in his 1982 'product-life factor' paper that extending product life reduces the depletion of natural resources and waste. Longer use of the products will thus contribute to the transition to a sustainable society. He indicates that the transition from the fast replacement system which is based on the linear economy where there is an exhaustion of natural resources and high consumption of energy and water and high production of waste to the self-replenishing system where the economy is based on a spiral loop system, will minimize matter, energy flow and environmental degradation without restricting economic growth or social and technical progress. We should keep the loops as small as possible and rely on the reuse, repair, reconditioning, and recycling of products [17].

In 1989, scientists Robert A. Frosch and Nicholas E. Gallopoulos, in their article "Manufacturing Strategies" focused on incentives for recycling, conservation, and switching to alternative materials by urging the transformation of the traditional manufacturing model of industrial activity into a more integrated model. An industrial ecosystem where energy and material consumption are optimized and the tributaries of a process are used as raw material. They also indicate that manufacturers and consumers must change their habits if the industrialized world wants to maintain its standard of living without harming the environment [18].

Although the term "Circular Economy" first appeared in the book "Environmental and Natural Resource Economics" in 1990 written by economists Pearce, D. and R. Turner [19] the very concept of the circular economy gained traction in 2002 with architect William McDonough and chemist Michael Braungart calling 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 is a model that provides sustainable benefits to society from materials, water, and energy in circular economies and eliminates the concept of waste. They educate their readers with examples and solutions based on the "reduce-reuse-recycle" method and encourage the manufacturing of products with an upcycling perspective [20].[21].

In parallel with the emergence of these theories about the circular economy, several environmental organizations in Europe, have been created to defend this cause. The implementation of the principles of a circular economy began with the creation of regulations on waste management and recycling [23]. We cite The Waste Disposal Act policy in Germany in 1976, the European Parliament and Council directive of 1994 about packaging and packaging waste [24], and the EU Waste Directive of 2008 [25].

In France, a new law was created in 1992, which defines new rules for waste management and prohibits landfills with the launch of a program for recovery and valorization of household packaging waste to make it a source of raw material and energy [10].

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 in order to achieve the EU's 2050 climate neutrality target [26].

One of the most important units advocating the concept of the circular economy and calling for its implementation is the Ellen Macarthur Foundation, founded in 2009. 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 [27]. In 2012, the foundation published its first report, the first of its kind, to consider the economic and commercial opportunities for the transition to a restorative circular model and the potential for significant benefits across the European Union [22]. The foundation continues its research to this day and is developing new ideas to accelerate the transition to circularity for different sectors and products like Plastics, Food, Fashion, Finance, and Cities [27].

Figure 2.1 summarizes the circular economy's main phases and evolution over time.

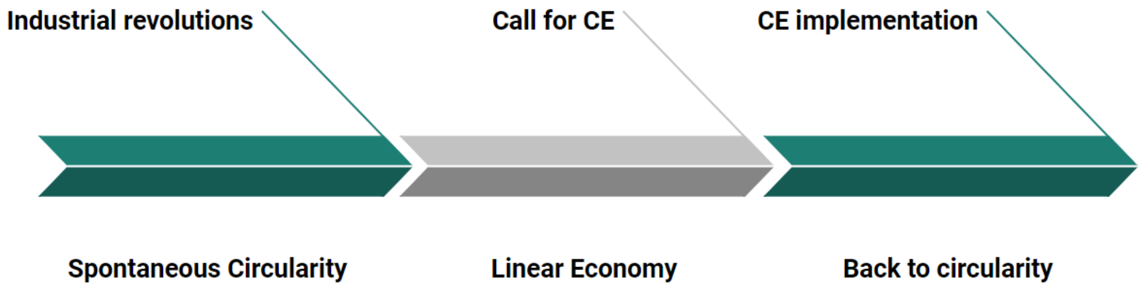

Figure 2.1: Different phases of the economy's concept

Despite the efforts made by the European Commission, the associations, and the non-governmental organizations, according to the Global Footprint Network, the most advanced overshoot day is the 29th of July 2021 [28]. This is the day when the ecological footprint has exceeded the biocapacity of the planet, that is, the moment when humanity has consumed all the planetary resources available for 2021 and therefore, has lived on credit until 2022.

2.3. The construction sector:

2.3.1. History of the circular economy in the construction sector:

The spirit of the circular economy was present even in prehistory. One of the main principles of the circular economy was applied to the Paleolithic period, which is recycling, where smaller flint tools were made from ancient hand axes [29].

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 [29].

For the Bronze Age period, it is especially characterized by the discovery and development of metallurgy. From 2500 BC., prehistoric people began to combine copper and tin to make a metal known as bronze. It was the main material of this period and, from the

Middle Bronze Age, it is recycled all over Europe. Its design was based on a transformation technology where the object is produced and has to be reproduced.

Several discoveries confirm this theory, such as that of the wreck found on the coast of Dover which contained a big quantity of French bronze objects dating from 1100 BC, destined for recycling in the United Kingdom [29].
In Hungary, spindle whorls made from fragments of broken pots have been found besides large stones that have been continually reused and repurposed, from millstone to anvil and from 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 [2].

New archaeological research at the site of Pompeii, the famous city destroyed by the eruption of Mount Vesuvius in AD 79, has shown that the ancient Romans recycled their waste, and profited from their efforts through artifacts found in the 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. [30] They were piled up, among other places, along almost the entire outer wall on the north side of the city. Some of these mounds were several meters high and included pieces of ceramics and plaster, which could be reused as building materials. [4] The walls contained discarded tiles, pottery shards, and other repurposed materials that had been coated to create a clean, even surface [30].

The Pompeians lived much closer to their trash than most of us would find acceptable, not because the city lacked infrastructure, and they didn't care about managing trash, but because their waste management systems in urban management were organized around different principles [31].

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].

For the remelting of glass, it is a habit dating back to the Late Bronze Age. This technique was based on the reuse of available or discarded glass objects for various reasons. A comparable 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 [32].

For the chemical analysis of the glass pieces, fuel ash slag, and furnace fragments found in the city of Sagalassos, it turned out that different silica-based raw materials were used in the imperial and early Byzantine periods for the blue and green glass found locally. The chemical composition of the found glass pieces, identical to that of the contemporary glass of the same color, strongly indicates that these pieces were used for the manufacture of green, colorless, and early Byzantine yellow-green glass at Sagalassos [33].

In the Egyptians, Greeks, and Romans, spontaneous circularity was applied 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 built before. From this period until the end of the 18th century, when buildings were transformed or deconstructed, posters were distributed everywhere around the site to inform of a public sale of the elements of the site for large builders as well as small artisans, to reuse them in other sites [34].

Figure 2.2 represents the timeline of the circular economy application in the construction sector from prehistory to the middle age, indicating the technic used for each period.

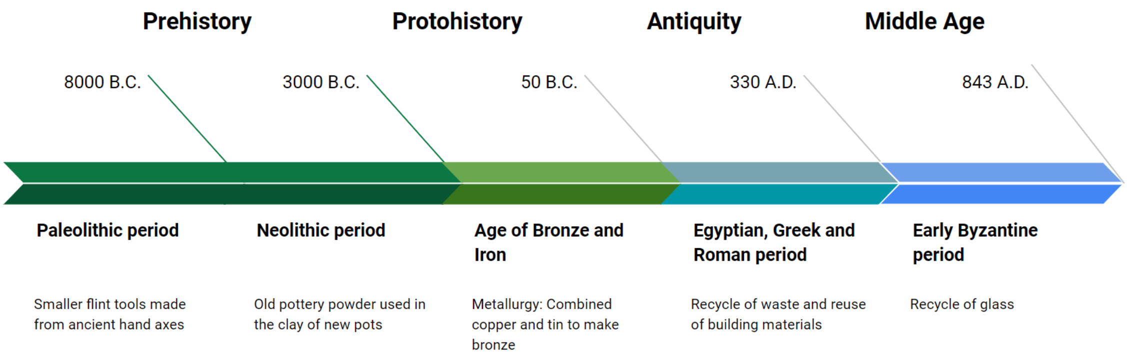

Figure 2.2: Chronology of the CE history in the construction sector

Until the 20th century, these techniques were common ways of dealing with material culture to combat the dominance of the wasteful linear economy of those times, until the industrial revolution started and got an enormous footprint on the environment.

2.3.2. Environmental problems in the construction sector:

The building sector is 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. These figures are the result of the environmental burdens that arise at different life cycle phases of buildings including the extraction of the raw materials for the manufacturing of the construction materials and products, the construction, operation, and maintenance of buildings, their demolition, and waste management [35].

2.3.2.1. Natural resources:

The construction sector is one of the biggest harvesters of resources, half of which are non-renewable. According to the World Watch Institute, the industry consumes 40% of the world's use of rough stones, gravel, and sand and 25% of its virgin timber annually [36].
The construction industry is a materially intensive sector that makes significant contributions to economic growth.

Globally, around 65% of total aggregates and approximately 20% of total metals are used by the construction sector to create the built environment (Krausmann et al., 2017). Over the past century, the overall use of construction materials (by weight) has increased by a factor of 42 and the same period has seen a 23-fold increase in the accumulation of in-use materials to 792 Gt [37].

Research by Kleiwerks says that building materials, such as concrete, aluminum, and steel, are directly responsible for “large quantities of CO2 emissions” due to high contents of “Embodied energy content”. Worryingly enough, construction activities consume “half of all the resources” extracted from nature, and account for one-sixth of global freshwater consumption, one-quarter of wood consumption, and one-quarter of global waste,” according to the research [38].

2.3.2.2. Waste:

Construction generates a massive amount of waste because it relies on quick and cheap solutions that need to be replaced every year, if not every few months. At the same time, recycling is still not required on construction sites, resulting in the waste of many valuable materials. [38] Besides, construction and demolition waste (CDW) is the most voluminous waste stream, accounting for over a quarter of all waste generated in the EU (European Commission, 2018) [38].

2.3.2.3. Atmosphere:

When it comes to air pollution, the production of carbon dioxide is one of the biggest contributors to global warming. This is due to actions on the construction site, transport, and manufacture of construction materials [36].

Construction is a relatively high contributor to air pollution, and air pollution causes can include land clearing, operation of diesel engines, demolition, burning, and working with toxic materials [39].

As anyone who has worked on-site will know, construction can generate a lot of dust, whether from building materials like cement and stone, from vehicles on-site, or from demolition activities – and there is a risk this dust can impact local environments [39]. The construction sector’s current practices at reducing pollutants, or omissions, are massively ineffective and may even “generate high levels of greenhouse gas pollution” [38].

Similarly, we must not forget another essential factor of air pollution: dust from a construction site. Created from cement, wood, or stone and often invisible to the naked eye, the dust is transported over long distances and for a prolonged period, this dust can cause serious health problems for humans and animals [36].

2.3.2.4. Biodiversity:

Noise may not be the first issue to spring to mind when it comes to the environmental impacts of pollution, but it is a potentially serious issue all the same. Clearly, construction sites can be noisy places, thanks to the extensive use of heavy plants, vehicles, and machinery. High levels of site noise carry a risk of affecting local residents and construction workers – but can also have an effect on local wildlife [39].

Noise and light pollution has a significant impact on fauna and flora, in particular bats, badgers, and birds, by disrupting their natural day cycle. However, this is only part of a much more complex problem.

Construction works have long-term effects on fauna and flora. To only cite a few: air and water pollution, hydrological impacts, isolation, and fragmentation of populations.
Such changes have a significant impact on animals, forcing them to change their way of life and reducing their population [36].

2.3.2.5. Water:

In construction, water pollution can occur when water containing pollutants from a site runs off into surrounding watercourses. The risks here can be as simple as heavily silted water being discharged into a nearby river or stream, known as sediment pollution, or less visible issues like surface water run-off containing harmful chemicals like paints, solvents, and diesel. Meanwhile, chemical pollutants can soak into groundwater, affecting drinking water [39].

It is well established that the construction industry can have major environmental impacts, but the true scale of the sector's pollution is laid bare by the numbers. Construction is believed to account for 4% of particulate air pollution, more water pollution incidents than any other industry, and thousands of noise complaints every year [39].

That is why there is a need to accelerate the transition to a circular economy and to move to the active implementation of the actions initiated by the European Union in all areas to protect the resources and the planet.

3. Materials and methods

3.1. Framing the circular economy principles:

Despite the different definitions given to the circular economy, its concept characterization brings together researchers from different fields where the circular economy is represented as a closed-loop system in which raw materials, components, and products lose value as little as possible, and renewable energy sources are used, and systems thinking is at the core [40].

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 [5]. The European Union's waste hierarchy in its 2008 Waste Framework Directive evolved the three Rs into Four Rs (reduce, reuse, recycle, recover). By 2017, ten separate Rs contributing to circularity had been identified, which are: Recover, recycle, repurpose, remanufacture, refurbish, repair, reuse, reduce, rethink and refuse, identified as E10RP [3].

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 CO_2, to reduce the environmental impact which is not directly represented by the existing E10RP [41].

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 the principles of Reduce, Rethink, and Refuse are concerned with decreasing the use of raw material [41].

Figure 3.1 represents the 10 Rs principles and their main role in the circular economy implementation.

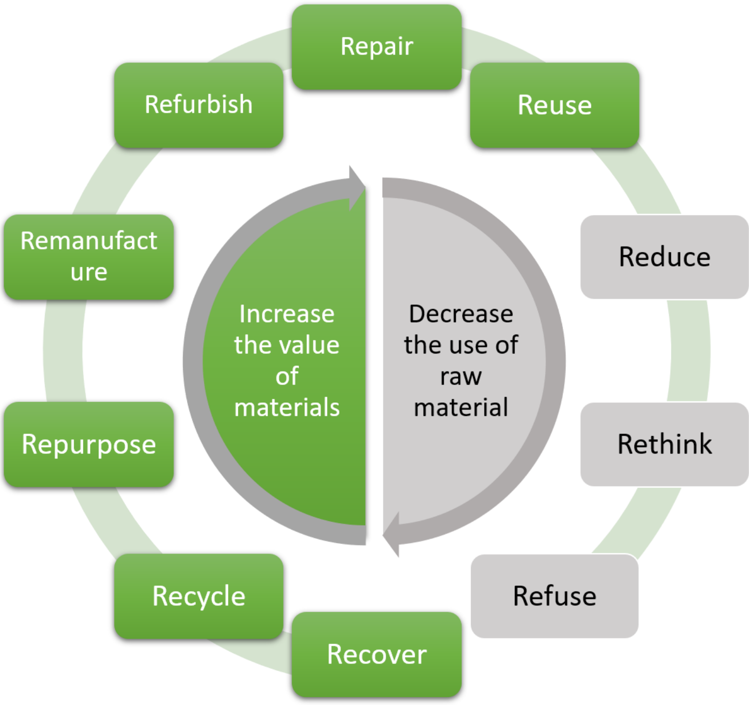

Figure 3.1: Circular economy's principles

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 fulfills 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

3.2. Resources and review process:

3.2.1. 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, a review was carried out in two different databases, namely Scopus and Web of Science. One chooses these databases for their access to numerous databases with content that comes 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 a wide variety of disciplines.

3.2.2. 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 phase of the screening is completed, the number of the remaining papers is stated in the table below.

For the first step, 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 obtain 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.

The second step was to add a set of keywords to the research previously made, to extract the publications on the subject of the principles of the circular economy. The chosen keywords are "Loop", "material flow", "CE principle", "Implementation principle" or "CE strategy". When developing the state of the art for the circular economy, these keywords were the most used to identify the circular economy principles (the R principles).

To be able to analyze the content, the third step was to only select the publications in English with access from the B-on platform.

For the fourth step, 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.

The last step was to select the publications that include the recycling principle, as it's 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.

Table 3.1: Review process

	Selection steps	Data Base		Total
		Scopus	Web of Science	
1	CE in the construction sector in European countries	997	753	1750
2	Papers with Keywords about CE principles	166	123	289
3	Papers in English with access from B-on platform	94	76	170
4	Papers selected after removing duplicated ones			87
5	Papers including "Recycle" principle			51

Despite obtaining 1750 publications concerning the circular economy in the construction sector, in Europe, only 2.9% of them were eligible for full-text reading and analysis. The results are presented in the next section.

4. Results and discussions

4.1. Results Description:

4.1.1. Publication trend by year:

Apart from the current year, the amount of publications has substantially increased since 2016 according to the research made en Scopus and Web of Science, which implies a growing interest from academia in the CE topic. This phenomenon can be explained by the significant concerns to translate circular thinking into the construction sector to support sustainable development further.

Although the term 'Circular Economy' appeared for the first time in 1990, the first research found on Scopus was published in 2001, untitled 'Current Status of home electric appliances recycling in Japan'.

Figure 4.1 represents the number of publications treating the concept of circular economy in all sectors per year, as well as in the construction sector, starting from 2001 until 2021. As indicated in the graph, an exponential increase in the number of publications related to the circular economy, and 2021 marks the year of the highest number, attempting 4829. Only 10% of this number involves the construction sector.

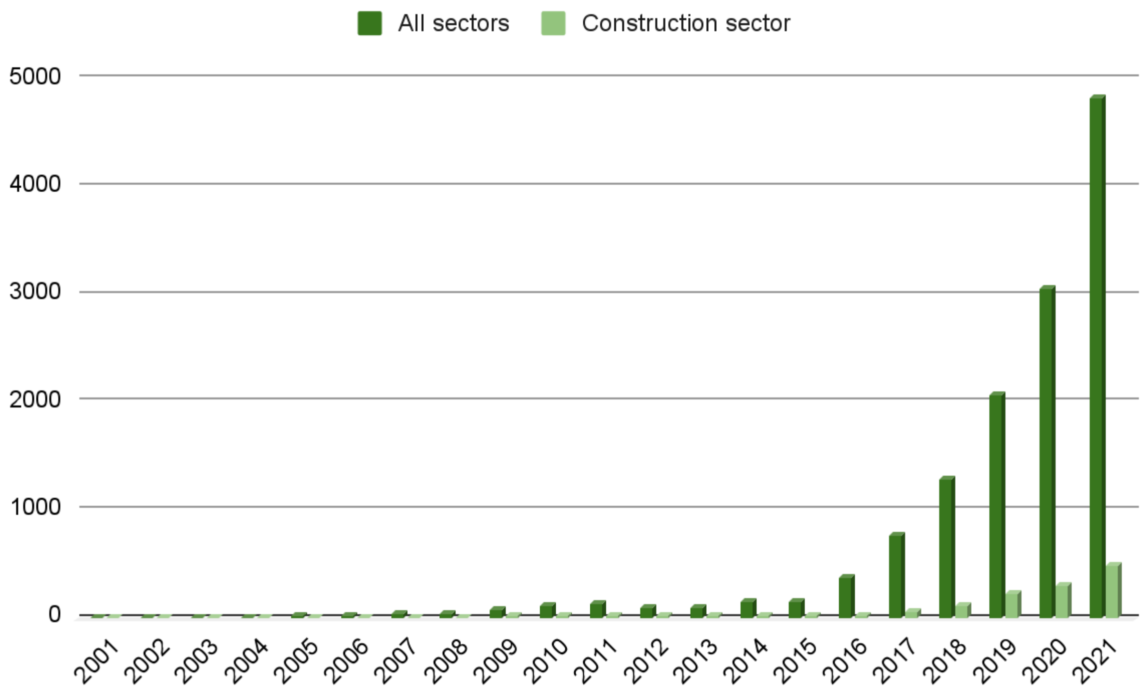

Figure 4.1: Number of publications per year in all sectors and in the construction sector via Scopus

Following the results obtained from Web of Science, the graph below, represents the circular economy publications trend in all sectors and in the construction sector, separately, starting from the first published paper on Web of Science until 2021.

14163 publications were found exploring the concept of circular economy, and only 9.5% of the total publications were directly related to the construction sector.

Figure 4.2: Number of publications per year in all sectors and in the construction sector via Web of Science

4.1.2. Publication trend by European country:

The analysis of the selected literature was done 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 UK came in the top three with 14.9%, 13.5%, and 11.5% fractions, respectively.

Figure 4.3 represents the fractions of different countries that contributed to these publications according to Scopus.

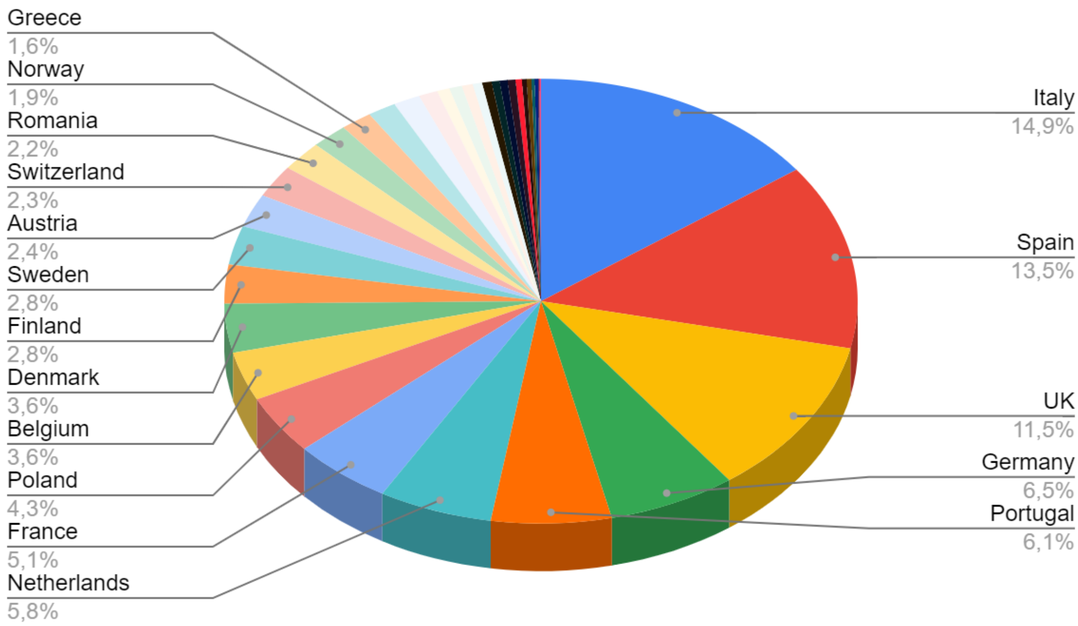

Figure 4.3: Fraction of CE publications per European country in the construction sector via Scopus

On the web of Science, European publications represented 55% of the total number of publications, with also, Spain, Italy, and the UK on top of the list with 12.6%, 12.3%, and 9.5% respectively.

Figure 4.4 represents the fractions of different countries that contributed to these publications, according to Web of Science.

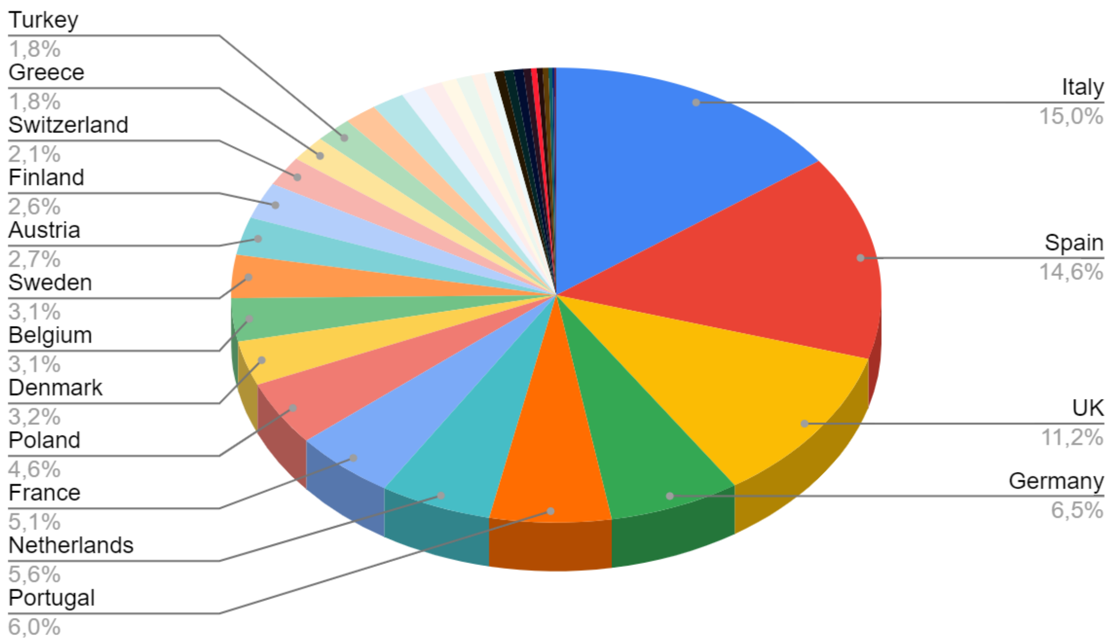

Figure 4.4: Fraction of CE publications per European country in the construction sector via Web of Science

4.1.3. Publications' subject and area:

After obtaining 997 publications in Scopus and 753 in Web of science exploring the circular economy in the construction sector, in Europe, as presented in section 3.2.2, a classification of these papers was made in accordance with the specific subject treated, relying on the keywords of each paper.

The main 145 common keywords used were divided into 13 groups depending on their meaning and common area, and are represented in table 4.1.

Table 4.1: 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%
Construction & Demolition 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%

As indicated in table 4.1, most studies focus on the promotion of the circular economy and waste recovery, rather than on the environmental impact of the construction sector and 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), and none of the rest of the R principles were listed as a keyword for these publications.

The design subject is treated in 12% of the publications, despite its contribution and importance in integrating the circular economy practices into a building's life stages.

Water pollution is mentioned in only 6% of the studies. This may be explained by the lack of acknowledgment of the process and possibilities of populating water as indicated in section 2.3.2.5.

Laws and legislation are the less studied area, with only 2%. The disinterest in this field is due to the lack of regulations and norms' application in the construction sector regarding the circular economy.

4.1.4. 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 4.2 summarizes, the relevant papers in alphabetic order, indicating the R principles taken into consideration, besides the principle ideas explored in each publication.

Table 4.2: Content analysis of the selected publications

Reference	Publication type	CE principles					LCA	Waste/ CDW	EoL	Design/ DfD	BIM
		Recycle	Reuse	Reduce	Recover	> 4 Rs					
42	review	+					+				
43	conceptual	+					+				
44	conceptual	+					+				
45	review	+					+				
46	conceptual	+					+	+			
47	experimental	+									+
48	conceptual	+					+				
49	review	+						+			
50	review	+						+		+	
51	review	+	+					+		+	
52	conceptual	+	+				+				+
53	conceptual	+	+					+			
54	review	+	+						+		
55	review	+	+		+		+				
56	review	+	+	+	+	+		+			

Reference	Publication type	CE principles					LCA	Waste/ CDW	EoL	Design/ DfD	BIM
		Recycle	Reuse	Reduce	Recover	> 4 Rs					
57	experimental	+	+	+	+	+	+			+	
58	review	+	+	+	+	+	+				
59	conceptual	+	+	+	+			+			
60	experimental	+	+	+	+	+				+	
61	experimental	+								+	
62	conceptual	+								+	
63	conceptual	+	+				+				
64	experimental	+	+	+	+	+	+	+	+	+	+
65	conceptual	+	+							+	
66	experimental	+	+	+	+	+					
67	conceptual	+	+	+				+	+		
68	conceptual	+	+	+	+			+	+		
69	review	+	+	+	+	+			+	+	
70	review		+		+						
71	experimental	+	+		+			+			+

Reference	Publication type	CE principles					LCA	Waste/ CDW	EoL	Design/ DfD	BIM
		Recycle	Reuse	Reduce	Recover	> 4 Rs					
72	review	+	+	+	+		+			+	+
73	review	+		+	+		+	+	+		
74	review	+	+		+						
75	conceptual	+	+	+	+			+			
76	review	+	+	+	+	+		+	+		
77	experimental	+	+					+			
78	review	+	+						+		
79	conceptual	+						+			
80	review	+		+	+			+	+		
81	review	+					+	+			
82	experimental	+	+	+	+	+				+	
83	experimental	+	+	+	+			+			+
84	review	+	+	+	+	+	+	+	+	+	

Reference	Publication type	CE principles					LCA	Waste/ CDW	EoL	Design/ DfD	BIM
		Recycle	Reuse	Reduce	Recover	> 4 Rs					
85	conceptual	+	+		+		+	+	+	+	+
86	conceptual	+	+					+			
87	review	+	+		+		+	+			
88	conceptual	+		+	+			+	+		
89	review	+	+		+		+				
90	review	+	+	+	+	+				+	
91	experimental	+	+	+	+			+	+	+	
92	review	+	+	+						+	

4.2. Content analysis:

4.2.1. LCA, CDW, EoL, BIM, and DfD:

As indicated in table 4.2, different subjects were analyzed in the selected papers, and 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)

The diagram below indicates the number of publications associated with each studied subject.

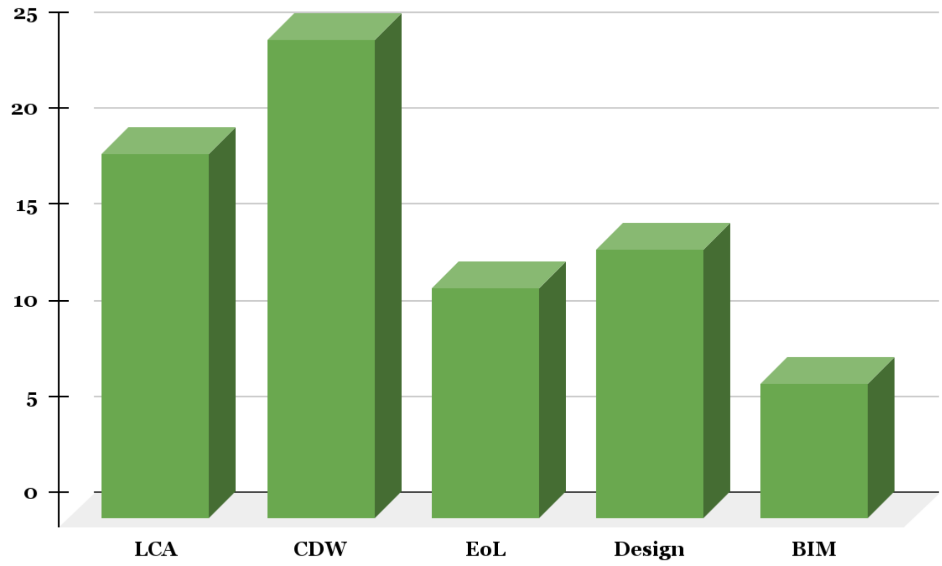

Figure 4.5: The diagram of the publications' area

According to figure 4.5, CDW is the most studied subject with 49% of the interest of the publication focused on the waste amount 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, where 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 methodologies of assessment.

Whether it's a life stage, a technique, or an approach, the "design" subject was treated 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 focus is given to the EoL stage, with 23% of papers subject 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.

Less importance is given to the BIM, despite its performance in presenting a built asset containing information about the building's geometry, material properties, and quantities of elements, with less than 14% of the papers investigating the subject.

In spite of the facilitation and performance of these parameters in implementing the CE strategies in the construction sector, they were only considered in 6% of the selected publications. As demonstrated in figure 4.6, these publications worked on finding an optimal combination of assessing the life cycle of buildings and components with searching for different ways of managing the CDW at the end-of-life stage, proposing ideas to design for disassembly and assembly of the construction in order to extend their lifespan and using BIM performance in collecting buildings' materials and component data to facilitate the process.

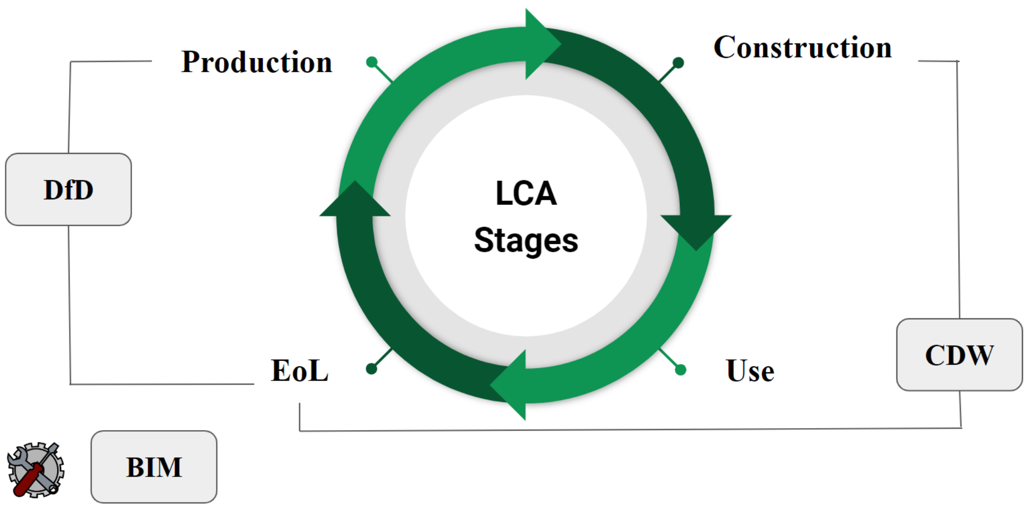

Figure 4.6: Link between LCA, CDW, EoL, BIM, and DfD

4.2.2. CE principles analysis:

41% of the publications didn't apply the CE principles, and only enlisted recycling and reusing as traditional practices that should be performed in the construction sector. These papers investigate only a specific subject related to the circular economy, without concerns about its principles.

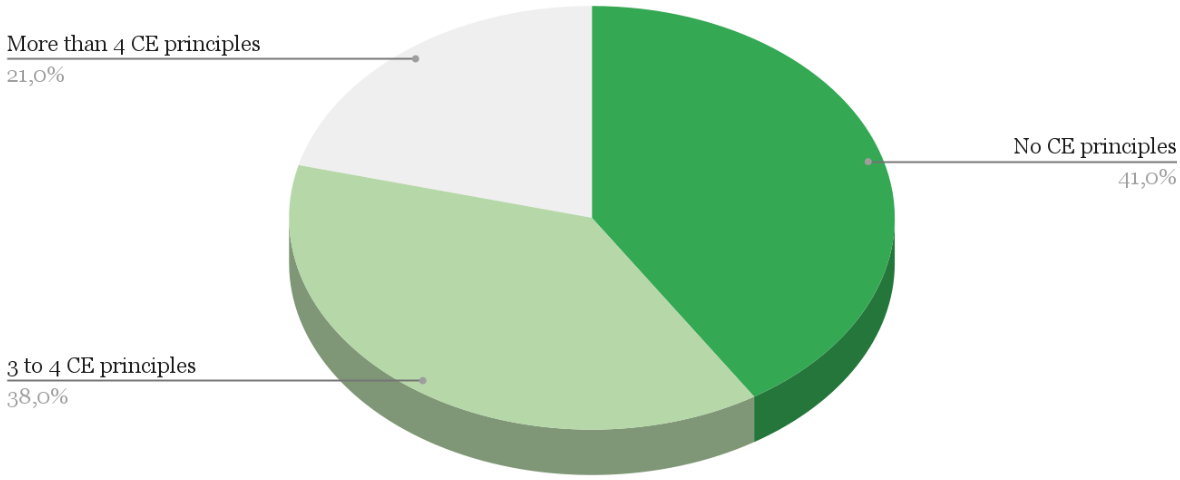

Figure 4.7: Selected publications fractions according to the CE principles number

As shown in figure 4.7, 38% of the selected publications, considered the 3R basic principles (Recycle, Reuse, Reduce). 64% of the publications that analyzed the CDW subject are included in this fraction.

21% of the publications had investigated more than 4 CE principles, and the figure below marks the involved papers with their assigned principles. The papers are identified by their number in table 4.2 and classified depending on the number of CE principles that each publication took into consideration, scaled from 1 to 11 associated respectively to Recycle, Reuse, Reduce, Recover, Repair, Refurbish, Remanufacture, Repurpose, Refuse, Rethink and Replace. The results are indicated in figure 4.8.

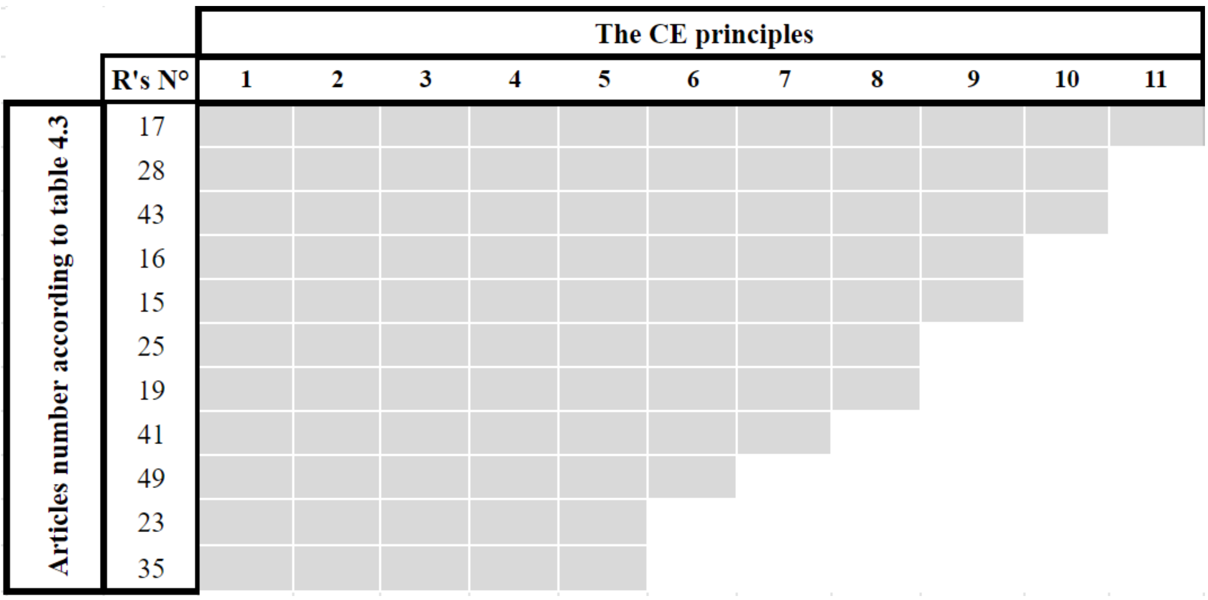

Figure 4.8: CE principles scales for the papers with more than 4R principles

In addition to the basic 4 R principles (Recycle, Reuse, Reduce, Recover), 100% of the publications indicated in Figure 11, considered the principle of “Repair” as it’s the easiest and most traditional way to extend the lifespan of a component or element.

“Refurbish”, “Remanufacture”, and “Repurpose” are also principles applied to extend the use stage in the life cycle of a building. These principles are considered in 63% of the papers that considered more than 4 of the CE principles, due to their potential in increasing the value of materials and in prolonging the lifespan of buildings.

For decreasing the use of raw materials, “Refuse” is a common practice that is considered in 45% of the last selected papers.

According to the results from figure 4.8, 21% of these publications analyzed the 10 CE principles, which represents 6% of the total. As previously indicated, 37% of the total selected papers took into consideration the LCA approach in their analysis. 36% of them 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 circular economy: A comprehensive literature review” [41], proposed a new principle for the circular economy, “Replace”. This principle is mainly concerned with introducing a new and more sustainable material alternative that is designed or manufactured to replace existing materials.

4.3. Discussion:

As indicated in the previous part, only 2.9% of the publications concerning the circular economy in the construction 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’s hard to close the loop as the “Recover” principle where heat, electricity, or fuel are retrieved from non-recyclable materials by incineration is never a good solution, especially in the construction sector where the building’s components are composite materials and cannot be considered as bio-waste and their incineration will be noxious to the environment.

As previously confirmed, in 41% of the selected studies, the R principles were not examined, instead, the Recycle and Reuse principles were cited as traditional practices for sustainability. The words “Recycle” and “Reuse” were used to promote the circular economy, without practically associating them with the implementation of CE in the construction sector as principles or parts of the concept’s strategy. Whether it’s 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.

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

According to the results indicated in figure 4.7 studies about implementing the CE principles were limited to 21% and the most relevant studies represent 6% of the selected papers, where the 10 R principles were examined and implemented in buildings and component life cycles.

Only one article, entitled "Selection Criteria for Building Materials and Components in Line with the Circular Economy Principles in the Built Environment-A Review of Current Trends" [84], succeeded in considering the 10 CE principles, besides the LCA, CDW, EoL, DfD, and BIM, the catalysts of the CE implementation in the construction sector, proposing a new practice of "the circular building" that embeds every aspect of the circular economy concept. It can be defined as a building that is designed, planned, built, operated, maintained, and deconstructed in a manner consistent with CE principles, and that 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 [57], [69], and [52], 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 principle where a product with dire impacts is depreciated into a redundant product with the same or better functions, the Rethink principle, where the material use is intensified for multiple uses or for economy shares, and the Reduce principle, where the efficiency of the element is increased but with less use of virgin materials.

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 principle, where a discarded material is reused by another user for the same function, the Repair principle, a damaged component is fixed for its initial performance, the Refurbish principle, where a component of a building is restored or renovated to make it like a new one, the Remanufacture principle, where a damaged building's parts are used for a new component with the same function, and the Repurpose principle, where a damaged building's parts are used for a new component too but with the different functions.

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, where the materials are integrated into the manufacturing and production process when a building reaches its end of life.

In the research made in the article [57] and [69], the Recover principle is associated with the third strategy, where heat, electricity, or fuel are retrieved from non-recyclable materials by incineration. In one's opinion, this principle may reduce the introduction of new raw materials and minimize the waste amount, but the incineration of the disposed materials will get the strategy steps back from circularity as from an environmental point of view, this operation is polluting and a source of dioxin emanation even in its most modern versions with an important production of toxic ashes.

The same can be stated for the new proposal of the "Replace" principle [41] may distinguish the publication from the other ones investigated in the 10 R principles, as it works on creating new materials or components to use in future building projects with lowering the level of CO_2 compared to the existing material, but will not cover the basic goals of the CE of increasing the economic value of the construction material or decreasing raw material usage and extraction.

4.3.2. 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 [69], one of the most crucial parameters in DfD is the choice of construction technology and how building elements will be assembled and disassembled. 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, which will allow building stakeholders to track materials, understand their origins, and assess their quality.

In the paper [64], the author proposed a Disassembly and Deconstruction Analytics System (D-DAS) which is 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 is to enable architects and design engineers to evaluate building designs for end-of-life sustainability performance from the design stage.

As concluded in the paper [68], to support waste minimization throughout building design stages, Architects should use BIM to simulate the most effective mode of construction, and the most sustainable and circularly project configuration. This 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.

As existing buildings are predominantly constructed to be demolished and not designed for deconstruction, the DfD approach cannot apply, and the merge of CE principles and 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 and more material reuse, repair, refurbish, recycle at their end-of-life.

After analysis of the selected papers, one conclude that the interest is turned to the new building construction instead of considering the design of the existing building for demolition and finding a technique to deconstruct buildings at their end of life, for ulterior assembly of new buildings or components instead of demolishing and losing an important amount of materials, increasing the pollution production and generating more waste.

4.3.3. Upcycling for a CE principle:

In the circular economy trend, Upcycle is considered a type of high-level recycling, while this technique can emerge as a practice of creative reuse of the buildings' elements.
As mentioned in the paper [62], 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. It addresses the existing architectural stock and its future use, not as a whole, but as separate upcycled modules.

As the Recover principle should be eliminated from the CE principles due to its harming impact on the environment despite its development, and due to its break of the closing loop process at 100%, it can be replaced by upcycling as a new practice integrated into the CE principles with the aim of discarding as few architectural components as possible and reduce or even eliminating waste. This method can be applied 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.

4.3.4. New CE framework for the construction sector:

One propose a framework for the CE principles adapted to the construction industry, where incineration is eliminated by removing the Recover principle from the loop, and the new Upcycle principle is added to extend the lifespan of the building and its components.

In the new framework, the CE principles are associated with all the life stages of the circular building, from the design and production until the end-of-life stage. This association is based on the main strategies adopted to design for assembly and disassembly, to manufacture sustainable materials, extend the lifespan of buildings, and manage them at their end of life.

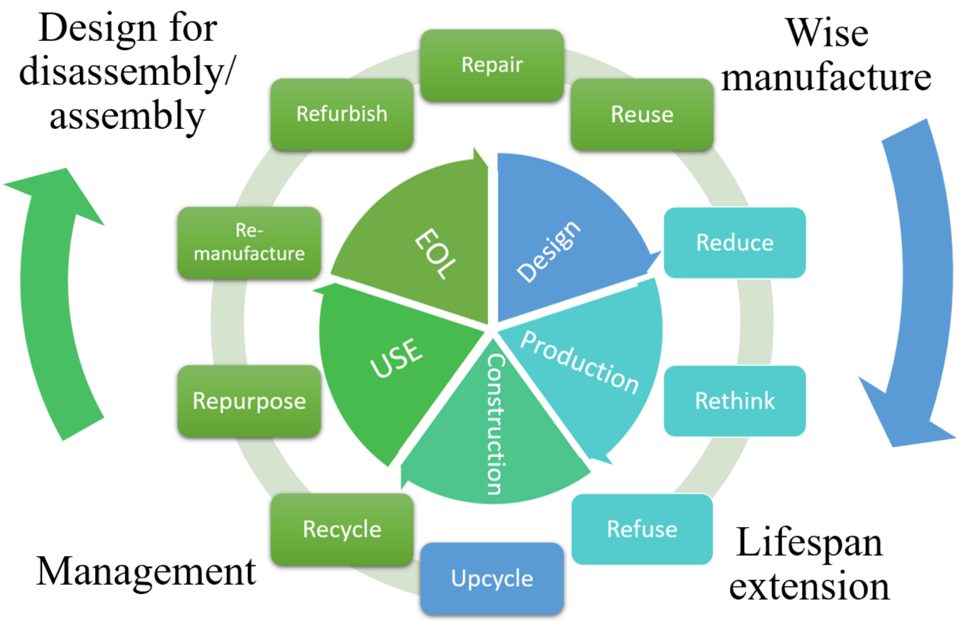

Figure 4.9: New framework for circular economy in the construction sector

As demonstrated in figure 4.9, by integrating the CE principles into the life cycle of buildings and construction materials, and adopting the right strategies during all the different stages with optimizing the solutions for circularity, closing the loop may be possible for a circular building, for less energy consumption, zero resources exploitation and zero waste generation.

5. Conclusion and future work

Researchers and stakeholders are missing the point of the CE implementation in the construction sector, while the focus is on proposing a new R principle or promoting a specific idea for circularity. The key to reducing the consumption of resources and waste production and retaining the value of resources as long as possible within the system through particular strategies is a combination between the R principles and the buildings and materials' life cycle evaluation.

A strategy for wise manufacture of materials for durability associated with Refuse, Rethink and Reduce principles, a strategy for extending the lifespan of buildings and their components by repairing refurbishing, remanufacturing, and repurposing new and existing materials, and a strategy for managing the end-of-life of buildings and a design strategy for disassembly and anteriorly for assembly. These strategies can be supported by the exploitation of the BIM performances, which will allow 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 it will support waste minimization throughout the building design stages.

Less interest is given to the existing buildings, where the design for demolition should be replaced by a technique to deconstruct buildings at their end of life, for ulterior assembly. For that matter, the "upcycling" principle is proposed as a new practice for the design strategy, with the aim of discarding as few architectural components as possible, eliminating waste, and especially, closing the loop at 100%. However, there is no significant research done in this area so far, bringing only 2% of the occurrences.

A great part of the studies, 41%, is still promoting the recycle and reuse as traditional practices that should be performed in the construction sector, investigating only a specific subject related to the circular economy, without concerns about its principles.

Despite the investigation of the CDW and its management, the operation of incineration in the framework of the "Recover" principle, is still practiced to retrieve energy at the end of the use of materials that become waste. For that matter, the "Recover" principle should be eliminated from the CE principles to guarantee closing the loop without harming the environment.

Besides the noxious practice of incineration, [41] proposed the "Replace" as a new R principle for the circular economy. Supposed to be mainly concerned with lowering the level of CO_2 by introducing a new and more sustainable material that is designed or manufactured to replace the existing one. But the author does not promote the basic goals of the CE of increasing the economic value of the construction material or decreasing raw material usage and extraction. Therefore, this principle should not be integrated into circular economy thinking.

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, 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.

Of all CE studies, only 10% are about the construction sector. Even though the percentage is low, the studies in the construction sector are supported, in the majority, by European researchers, due to the awareness work done by different stakeholders of the sector and the European commissions.

Most of the trending studies, 92%, are dedicated to the promotion of the circular economy concept through construction materials, rather than analyzing the impact of the construction sector on the environment and finding solutions for a 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.

Despite its splendor and revolutionary effect throughout the world and the rapid social and economic development in the history of mankind, industrialization has distanced us from the practices and habits of everyday life that support the principles of circularity that protect the environment and natural resources due to the easy access to them and the growth of human needs.

Realizing that human activities had damaged the environment, causing the scarcity of resources, production of harmful gases, and waste generation, researchers and commissions are working on getting back to circularity with new practices and benefiting from the technologies' development by promoting the circular economy.

For a better implementation of the circular economy's principles, the proposed framework should be tested in a case study, where the theoretical understandings must be assigned to each practical work and activity of the construction sector.

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