NOVA SCHOOL OF SCIENCE & TECHNOLOGY

DEPARTMENT OF ENVIRONMENTAL SCIENCES AND ENGINEERING

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Bachelor's in Environmental Engineering Sciences

PROMOTING SUSTAINABILITY IN THE CONSTRUCTION SECTOR: ASSESSMENT OF THE REUSE OF CONSTRUCTION MATERIALS

INTEGRATED MASTER IN ENVIRONMENTAL ENGINEERING, PROFILE OF SANITARY ENGINEERING

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Promoting Sustainability in the Construction Sector: Assessment of the Reuse of Construction Materials

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ABSTRACT

There is a growing awareness of the need to address certain environmental impacts on the planet, such as waste management. The construction sector has emerged as a significant consumer of raw materials, as well as a major contributor of construction and demolition waste (CDW). Effective management of this type of waste is critical to minimising the environmental impact and overall footprint of stakeholders. It is a considerable challenge and highlights the need for initiatives to develop circular economy approaches to value construction materials rather than letting it become waste. Among these approaches, the reuse of construction materials stands out as an effective practice for reducing the environmental pressure associated with this sector.

The aim of this study is to investigate the progress of reuse practices in European Union countries, particularly in the construction sector, after the implementation of several regulations such as the Waste Framework Directive 2008/98/EC (amended by Directive 2018/851). Another objective was to identify the barriers and drivers that influence the adoption of reuse in construction companies. Furthermore, the research aims to outline effective strategies and best practices to promote this practice in the sector. In order to achieve these objectives, a systematic literature review was conducted, providing a unique assessment focused on analysing the impact of the European Union strategies and legal frameworks implemented to promote reuse, and how these policies have influenced the direction of research in this field through the results obtained with the methodology designed.

It was concluded that the field of research has evolved over time, and it was possible to identify the main barriers and drivers related to reuse. The articles obtained were mainly observed in the period from 2018 to 2023, with a significant contribution from countries such as Portugal, Italy, Spain, Finland, Belgium, and Sweden and focused on the strategies that can be implemented in the construction sector in the perspective of a circular economy. The aim of defining strategies to promote reuse was also achieved. In this way, companies,

decision-makers and other stakeholders in the sector can make better decisions to promote sustainable practices.

Keywords: Reuse, circular economy, waste hierarchy, construction sector, construction materials, construction and demolition waste (CDW), systematic literature review

RESUMO

Existe uma consciência crescente acerca da necessidade de abordar certos impactos ambientais no planeta, como é o caso da gestão de resíduos. O setor da construção emergiu como um consumidor significativo de matérias-primas, bem como um dos principais contribuintes na produção de resíduos de construção e demolição (RCD). A gestão eficaz deste tipo de resíduos é fundamental para minimizar o impacto ambiental e a pegada ambiental das partes interessadas. Trata-se de um desafio considerável e realça a necessidade de iniciativas para desenvolver abordagens de economia circular para valorizar os materiais de construção em alternativa a se tornarem resíduos. Entre estas abordagens, a reutilização de materiais de construção destaca-se como uma prática eficaz para reduzir a pressão ambiental associada a este setor.

O objetivo deste estudo foi investigar o progresso das práticas de reutilização nos países da União Europeia, particularmente no setor da construção, após a implementação de vários regulamentos, como a Diretiva 2008/98/CE (alterada pela Diretiva 2018/851). Outro objetivo foi identificar as barreiras e os fatores que influenciam a reutilização nas empresas de construção. Além disso, a investigação visou delinear estratégias eficazes e boas práticas para promover esta prática no setor. Para atingir estes objetivos, foi realizada uma revisão sistemática de literatura, proporcionando uma avaliação única centrada na análise do impacto das estratégias e enquadramento legal da União Europeia implementados para promover a reutilização, e como estas políticas influenciaram a direção da investigação nesta área, através dos resultados obtidos com a metodologia concebida.

Concluiu-se que a investigação nesta área tem evoluído ao longo do tempo, tendo sido possível identificar as principais barreiras e impulsionadores relacionados com a reutilização. Os artigos obtidos foram observados maioritariamente no período de 2018 a 2023, com uma contribuição significativa de países como Portugal, Itália, Espanha, Finlândia, Bélgica e Suécia e focam-se principalmente nas estratégias que podem ser implementadas no setor da

construção na perspetiva de uma economia circular. Foi também atingido o objetivo de definir estratégias para promover a reutilização. Desta forma, empresas, decisores e outros intervenientes do sector podem tomar melhores decisões para promover práticas sustentáveis.

Palavras-chave: Reutilização, economia circular, hierarquia de resíduos, setor da construção, materiais de construção, resíduos de construção e demolição (RCD), revisão de literatura sistemática

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ABBREVIATIONS

BIM - Building Information Modelling

BPEO – Best Practicable Environmental Option

CDW/C&DW - Construction and Demolition Waste

CE - Circular Economy

CLOSER – Close to Resources Recovery Project

EU - European Union

GDP - Gross Domestic Product

LNEC – National Civil Engineering Laboratory

LNEG – National Laboratory of Energy and Geology

MP - Material Passport

PP – Proximity Principle

SLR - Systematic Literature Review

WH - Waste Hierarchy

1. INTRODUCTION

1.1. General Context

There is currently a growing awareness of the need to take action on pressing environmental issues (Calculli et al., 2021) and to put in place measures to enforce such action. The problem of the anthropogenic impact on the planet has been observed for a long time and has been studied over the years by various researchers in different scientific fields, and it is possible to observe, for example, several effects on climate changes over the years (Abbass et al., 2022). As some human activities continue to grow, so does the impact on the planet. This brings with it new challenges. An example that needs more and more attention is the constant increase in the amount of waste produced (Abdel-Shafy & Mansour, 2018; Razzaq et al., 2021; World Bank, 2021). As a result, there is a need for new developments in the field of waste management. Without it, the problem will continue to contribute to several issues such as pollution (Siddiqua et al., 2022), resource depletion (Gao et al., 2023; Haas et al., 2015; Secco et al., 2022) and ecosystem degradation (Tyagi et al., 2014; Wu et al., 2022).

The construction sector has a significant impact on the environment through its use of the planet's raw materials (W. Chen et al., 2022; Marinković et al., 2010), but also through its role in the generation of large amounts of Construction and Demolition Waste (CDW) (Cheng et al., 2022; Hasan et al., 2022; Piñeiro et al., 2015). On a global scale, this sector is responsible for the consumption of 20% to 50% of natural resources (Vasilca et al., 2021), and when looking at the European Union (EU), it represents approximately 37% of the total waste generated annually (Eurostat, 2020). Another problem directly related to this is that CDW is often disposed of in landfills due to the improper management of this waste (Ginga et al., 2020).

In order to overcome the environmental problems caused by these activities, the concept of a circular economy (CE) needs to be promoted in the construction sector (Al Zulayq et al., 2021; European Commission, 2020). The sector should focus on promoting the value of certain materials contained in CDW as resources rather than wasting them

(Papastamoulis et al., 2021). In this perspective, the generation and disposal of CDW should be reduced and construction materials should be managed in sustainable ways (Khan et al., 2022). In addition to the positive aspects for the environment (Eberhardt et al., 2022), this perspective also has several positive consequences for construction companies, such as decreasing pressure to reduce their environmental impact (Geissdoerfer et al., 2017). There are many methods that can be used to encourage this type of practice, some of which are already in place, such as regulations that can be implemented to encourage the reuse and recycling of materials (Ghaffar et al., 2020). In the EU, one of these important initiatives is the implementation of the European Commission Waste Framework Directive 2008/98/EC, which sets out measures to protect the environment by preventing and reducing the impacts of waste generation.

From this point of view, the practice of reusing construction materials can be very beneficial because it could represent a lower environmental impact (Xia et al., 2020). However, reuse is not yet a common practice among EU construction companies, as is the case in Portugal (Antunes et al., 2021). In this context, in order to promote this method in the construction sector, it's important to study and understand the state of the art about the main barriers and drivers of this process. Then, as a next step, it is important to define and promote best practices and strategies that increase this practice (Nußholz et al., 2019).

1.2. Research Purpose

The main objective of this dissertation is, firstly, to better understand the concept of reuse and to study the development of this practice for construction materials in EU countries after the implementation of the European Commission Waste Framework Directive 2008/98/EC (amended by Directive 2018/851) and other implemented policies. Furthermore, through a systematic literature review, the study aims to analyse how the strategies and legal frameworks implemented by the EU to promote reuse in the construction sector have influenced the direction of research in this field. It also aimed to identify the main barriers and drivers associated with this practice.

The final objective of the study is to better understand the current problems hindering the implementation of this practice and, consequently, to propose effective strategies and best practices to promote reuse in the construction sector in EU countries.

1.3. Document Structure

This dissertation is structured in six chapters, as follows:

Chapter 1 - Introduction

In this chapter, a brief introduction has been made to the subject that has been studied in this dissertation. It presents the challenges posed by the construction sector and introduces the problem of the amount of CDW in this industry as well as highlighting the importance of reuse, since this is the main focus of the dissertation. A subchapter has also been added introducing the main research purpose of this study.

Chapter 2 - Literature Review

A literature review was carried out, where the issue of CDW was introduced in more detail, as well as the definition of the circular economy and the concept of reuse, in order to better understand how this process can serve as a benefit for the introduction of more sustainable activities in the construction sector. In addition, a legal framework of the regulations implemented by the EU and by Portugal was carried out in this chapter. Some methodologies and technologies already in use and under development have also been presented.

Chapter 3 - Methodology

This chapter presents the methodology used to carry out this study, specifically a Systematic Literature Review (SLR), identifying the criteria used to develop it within the area of study.

Chapter 4 - Results and Discussion

This section presents the results of the SLR and the findings regarding the research questions defined at the beginning of the research, and discusses the results obtained.

Chapter 5 - Proposed strategies and best practices

This chapter introduces and proposes new strategies and best practices to be implemented by companies, decision-makers and other stakeholders in the construction sector to promote reuse, based on the findings of the systematic literature review.

Chapter 6 - Conclusions

Finally, this chapter presented the main conclusions drawn from the study conducted in the present dissertation. The main limitations of the study and recommendations for the development of future studies in this area have also been presented.

2. LITERATURE REVIEW

The construction sector plays an important role in the economic development around the world (Alaloul et al., 2022; Oladinrin et al., 2012). It contributes to the development of countries by providing various types of benefits such as employment opportunities, investment, infrastructure, and transport (L. Huang et al., 2018). However, this sector is also responsible for causing impacts on the environment (A. Sharma et al., 2018; Tam et al., 2004; Vaverková et al., 2019), consuming a lot of resources (Fei et al., 2021) and energy (L. Huang et al., 2018), in addition to producing high volumes of CDW (Cheng et al., 2022; Hasan et al., 2022) which makes it sometimes difficult to manage.

This literature review is structured in an effort to understand the issue of CDW management and the subsequent areas that are directly related to this management. The review begins with an introduction to the construction sector, followed by an overview of the challenge of CDW management. This is followed by a chapter introducing the circular economy perspective, followed by a sub-chapter introducing some key concepts that are essential for understanding this topic. Then, it is followed by an introduction to the waste hierarchy and the importance of the practice of reuse (included in the hierarchy) in the construction sector, which is the main focus of the dissertation. In addition to the literature review, separate chapters present the regulations implemented by the EU, including the case of Portugal, since it is the author's country where this research took place. These chapters are important for understanding the legal mechanisms that support the management of this type of waste in the areas studied. Finally, there is an introduction to different innovative approaches that promote reuse in the construction sector.

The aim of this literature review is to provide a comprehensive view of CDW management, but above all to assess the practice of reuse in a circular perspective in the construction sector.

2.1. The Construction Sector: Addressing Circularity Challenges

2.1.1. The Construction Sector

The construction sector has a high global impact, contributing to the development of services necessary for the prosperity of countries. This sector represents several economic activities, such as the extraction of natural resources, manufacture of construction products, new construction, rehabilitation, and demolition activities (European Commission, 2016b). In consequence, other benefits of the sector include its impact on the economic growth of countries (Hatem et al., 2022).

According to the European Commission (2016), the construction sector is a key economic driver in EU countries, accounting for around 9% of gross domestic product (GDP) and contributing to the employment of over 20 million people. The European Union's single market also offers international partners access to a market of more than 500 million people and a GDP of around 13 trillion euros. This economic activity is classified as Section F ("Construction") in the Statistical Classification of Economic Activities in the European Community (NACE).

However, activities in this sector also have many negative aspects for the environment (Buyle et al., 2013; Ding et al., 2017; Horvath, 2004) that can be linked to other factors related to the sector, such as the high energy consumption required (Tabrizikahou & Nowotarski, 2021; Xu & Wang, 2020; Y. Zhang et al., 2019). Other negative impacts include the loss of territories due to the extraction of natural resources (Cai & Waldmann, 2019a), the establishment of new landfills (Marinković et al., 2010) and the emission of pollutants (Li et al., 2017), such as CO_2 emissions (Arıoğlu Akan et al., 2017; L. Huang et al., 2018). In the EU area, the construction sector is responsible for around 36% of CO_2 emissions (Cellura et al., 2018). Other impacts include noise pollution, waste generation and water consumption (Omer & Noguchi, 2020) and pollution, in general (Chuai et al., 2021). More precisely, this waste represents around 37% of the total waste generated in the EU (Eurostat, 2020).

2.1.2. The Construction and Demolition Waste Challenge

According to the Directive (EU) 2018/851, of the European Parliament and of the Council, of May 30th, amending the Waste Framework Directive 2008/98/EC, of the

European Parliament and of the Council, of November 19th, the definition of CDW is any construction and demolition waste, which refers to waste resulting from construction and demolition activities in general, including waste from Do It Yourself (DIY) activities involving construction and demolition in private households.

In the context of the European Union, CDW is the most significant waste stream by volume, accounting for one third of all waste generated (European Commission, 2018a). The distribution of waste generation by economic activities and households in the EU countries is shown in Figure 2.1.

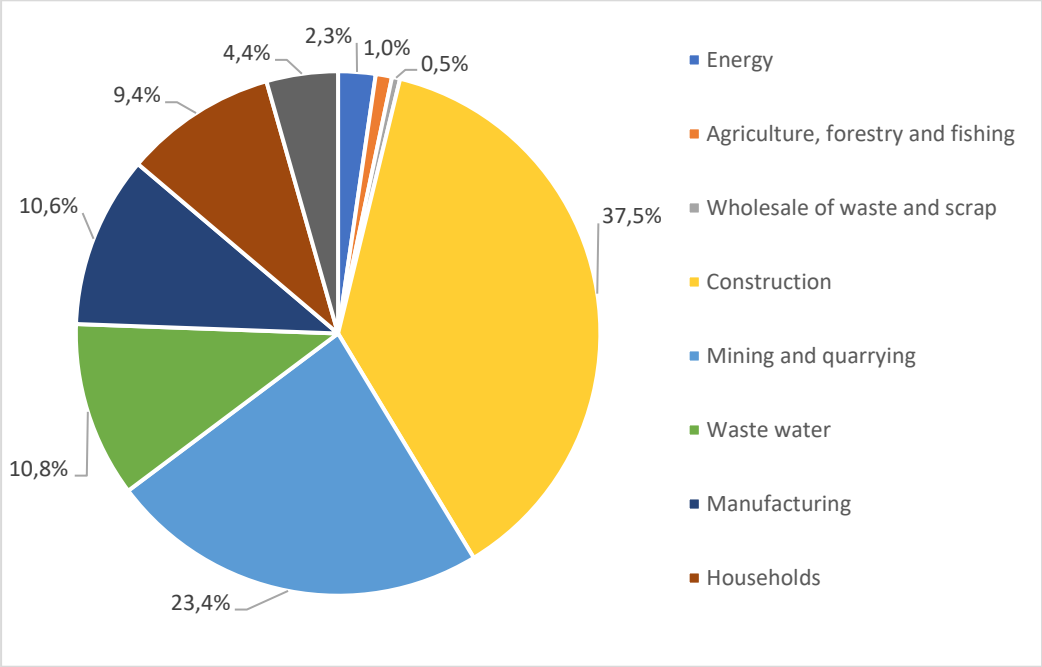

Figure 2.1. Waste generation by economic activities and households (Eurostat, 2020)

CDW can consist of and be classified as a mixture of inert and non-inert materials (X. Chen & Lu, 2017), as well as hazardous and non-hazardous waste (Y. Chen & Zhou, 2020). This type of waste has a characteristic that makes it difficult to manage: it is heterogeneous, with different dimensions and different levels of hazardousness. In addition, its geographical dispersion regarding its generation at construction sites and the time factor of the interventions make it difficult to achieve environmental targets in this sector (LNEC, 2022). This characteristic of heterogeneity can also have negative aspects in the management of this waste stream, due to the lack of training and organisation of the construction workers responsible for managing it (Galán et al., 2019; Ramos, Martinho & Pina, 2023; Ramos et al.,

2023, Ramos & Martinho, 2021). Other factors hindering the management of this type of waste are the lack of design standards to reduce the amount of CDW generated, the lack of guidelines and standards for the collection and separation of CDW (Luciano et al., 2022), the lack of a developed market for reusable or recycled materials (B. Huang et al., 2018) and the lack of confidence of construction companies and other stakeholders to use this type of construction material (Ramos & Martinho, 2022). In addition, there is still a lack of infrastructure for CDW management, such as infrastructure for recycling or for transporting recovered materials after the demolition phase, and places to store this type of resource (Negash et al., 2021; Pimentel et al., 2022).

One of the main problems associated with the generation of these large quantities, as mentioned above, is the landfilling of waste rather than using other waste management options (Ginga et al., 2020). However, another related problem is that this waste is still often abandoned, which is an illegal practice (B. Huang et al., 2018; Luu et al., 2021a; Ramos & Martinho, 2023). Illegal dumping is defined as intended depositions of waste in locations not legalised for such purpose (Liu et al., 2022).

Illegal dumping can have a significant impact on the environment, such as deterioration of water quality, degradation of soil quality and an increase in nitrates in the soil, which can also affect human health (Kabirifar et al., 2020; Limoli et al., 2019; Luu et al., 2021a). Fires can also be caused by this illegal activity (Giovannini et al., 2014) and it also causes costs linked to the need to decontaminate and restore landscapes (Luu et al., 2021b). The causes of this problem are many and varied, from the level of development of waste management systems in each country, to the level of control and fines imposed by each nation for committing this illegal act, to the costs associated with legal landfill (Matos et al., 2012; Ramos & Martinho, 2023).

It is therefore necessary for this sector to approach the management of its waste from the perspective of preventing a percentage of CDW from actually becoming waste, but rather from becoming materials that can be further utilised in a variety of ways (Khan et al., 2022).

2.2. The Circular Economy Approach

Over the years, the construction sector has been dominated by a linear economy (LE) perspective, which is still quite prevalent today and is generally known as the "take-make-dispose" approach (Guerra & Leite, 2021). This model focuses only on the

consumption of natural resources, the production and disposal of the material at the end of its useful life, without considering its value for further use (Sharma et al., 2021).

In contrast to this approach, there is a CE perspective, which is becoming more popular because of the need to reduce the amount of CDW produced in the construction sector (Torgautov et al., 2021). The concept of CE has several definitions, according to different authors (Leising et al., 2018a). According to Kirchherr et al. (2017), who analysed 114 different definitions of the concept of CE, it can be defined as follows:

- CE is an economic system that replaces the concept of disposing of a material with the perspective of trying to reduce, reuse, recycle or recover the material itself. This concept can be applied at the micro level as well as at the meso or macro level of companies, industries, nations, and more;
- The CE vision also aims to seek the good of future generations by enabling sustainable development in which the quality of the environment, as well as economic and social development, can be guaranteed. This evolution can be achieved through new economic models and through responsible consumers;

The transition from a LE to a CE requires several changes, from the initial material creation phase to the nature of the market, as well as innovations in the area of waste management (Gorecki, 2019). Figure 2.2 shows the difference between the perspective of a LE (a) and a CE (b).

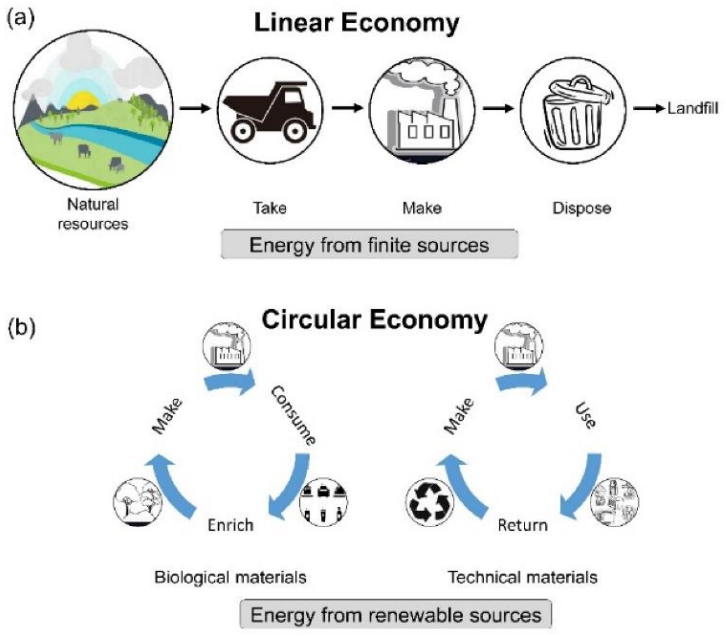

Figure 2.2. Difference between the LE (a) and the CE (b) (Al Zulayq et al., 2021)

According to (Baldassarre et al., 2019), implementing this CE perspective requires three main strategies of closing, slowing and narrowing/reducing loops:

- Closing loops refers to the creation of a circular flow of resources from the use phase, which are generally considered to be waste;
- Slowing loops is concerned with prolonging the use and reuse of a component through measures such as repair, refurbishment and remanufacturing;
- Narrowing loops is about reducing the use of resources and maximizing the efficiency of production processes;

The CE approach is a strategy that can consequently reduce resource depletion and the amount of CDW generated (López Ruiz et al., 2020; Ottosen et al., 2021). Although the prospect of a CE is growing, as mentioned above, more research is needed in this area to understand what factors may be hindering the implementation of this concept in the construction industry (Bilal et al., 2020), such as legal, technical and behavioural factors that need to be resolved (Christensen et al., 2022). In order to achieve this, it is necessary to adopt a number of waste management strategies, which in turn will reduce the amount of CDW ending up in landfills and help generate new jobs (Ilić & Nikolić, 2016). In addition, a variety of stakeholders across the whole chain need to change their traditional practices to more sustainable ones (Christensen et al., 2022). Thus, this circularity approach can help solve and respond to several megatrend issues, such as increasing urbanisation and climate change (Joensuu et al., 2020).

2.2.1. Understanding Key Concepts

In the context of CE, there are several concepts directly related to it, and it is important to understand the definitions of these concepts for the purposes of this study. Several of these concepts can be defined according to the European Commission Waste Framework Directive 2008/98/EC, which are presented below:

- Waste: any substance or object which the holder discards or intends or is required to discard;
- Waste Management: the collection, transport, recovery (including sorting), and disposal of waste, including the supervision of such operations and the after-care of disposal sites, and including actions taken as a dealer or broker;

- Waste Producer: anyone whose activities produce waste (original waste producer) or anyone who carries out preprocessing, mixing or other operations resulting in a change in the nature or composition of this waste;
- Prevention: measures taken before a substance, material or product has become waste, that reduce: (a) the quantity of waste, including through the re-use of products or the extension of the life span of products. (b) the adverse impacts of the generated waste on the environment and human health. (c) the content of hazardous substances in materials and products;
- Reuse: any operation by which products or components that are not waste are used again for the same purpose for which they were conceived;
- Preparation for reuse: means checking, cleaning or repairing recovery operations, by which products or components of products that have become waste are prepared so that they can be re-used without any other pre-processing;
- Recycling: any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes. It includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations;
- Recovery: any operation the principal result of which is waste serving a useful purpose by replacing other materials which would otherwise have been used to fulfil a particular function, or waste being prepared to fulfil that function, in the plant or in the wider economy;
- Disposal: any operation which is not recovery even where the operation has as a secondary consequence the reclamation of substances or energy;

There are other important concepts in waste management that are not defined in the Directive, such as the practice of selective demolition. According to Chau et al. (2017), the concept of selective demolition can be defined as follows: the practice of systematically dismantling a building to facilitate the collection of materials for later reuse. This practice therefore maximises the amount of material that can be recovered and reused (European Commission, 2018b).

This type of practice has several advantages over traditional demolition, including the recovery of materials that can be used in a more sustainable way (Gálvez-Martos et al., 2018), such as reuse, as already mentioned, or recycling (Anastasiades et al., 2023). It also reduces

environmental pollution such as carbon emissions (Xiao et al., 2023), and creates new job opportunities (Anastasiades et al., 2023). There are also some disadvantages to this practice, such as the need for additional time and resources (Gálvez-Martos et al., 2018), as well as the occurrence of damage during the process, as current buildings were not designed with deconstruction in consideration (Anastasiades et al., 2023). The deconstruction of different buildings can also vary depending on the equipment used and other technical aspects, so it is important to make an initial assessment and analyse the various factors that characterise each demolition project (Xiao et al., 2023).

Although this practice has a number of aspects that can be considered negative, it has emerged as a more sustainable option and for it to be implemented in the construction sector, a number of changes need to be made to the various project phases (Allam & Nik-Bakht, 2023). In addition, various studies are being carried out to combine this practice with new technologies and combining it with certain technological innovations can bring benefits such as increasing the efficiency of the process (Akbarieh et al., 2020).

2.2.2. The Waste Hierarchy

In the context of the CE perspective, there is the concept of the Waste Hierarchy (WH). The WH is a vision that has been discussed for many years and can be seen as a reference since the 1970s, with this perspective often appearing as a form of education in social dialogue as the concept "reduce, reuse, recycle" to promote a development in waste management (Gertsakis & Lewis, 2003).

According to the European Commission Waste Framework Directive 2008/98/EC, the WH must be complied with in order to achieve better waste management and the concept presents five different concepts with different order of priority, starting from the most prioritised to the least desired: Prevention, Reuse, Recycling, Other Recovery, Disposal.

Figure 2.3 shows these concepts in the order of priority defined.

Figure 2.3. Waste management hierarchy (European Commission, 2023)

The WH puts the act of disposal last and the option of preventing the amount of waste produced first, as would be expected, with waste reduction bringing advantages (Price & Joseph, 2000).

Despite the good vision created by this hierarchy, many municipalities in several countries still struggle to manage their waste in this way and end up using practices further down the hierarchy (Adipah & Kwame, 2018). In addition, countries must not only follow the WH vision, but also consider other relevant factors such as the economics of waste management. For example, a waste stream may have the potential to generate an economic benefit, but there are costs associated with transporting it (C. Zhang et al., 2020).

According to Adipah & Kwame, (2018), in addition to the WH, there are other methods to promote sustainable development in waste management, such as the Proximity Principle (PP) and the Best Practicable Environmental Option (BPEO). The PP advocates disposing of waste as close as possible to where it is generated to reduce the time and energy spent on transport. BPEO encourages practices that are best in terms of energy, cost and time, while having the lowest possible impact on the environment.

In the context of CDW management, the WH has set out the most appropriate way to manage this type of waste, and there are significant environmental benefits in using this hierarchy and creating ways to manage construction materials according to the first actions it prioritises (Buchard & Christensen, 2023; Marinho et al., 2022). The use of this hierarchy makes

it possible to manage the large quantities of CDW produced by encouraging the closure of supply chain loops as far as possible (Ranjbari et al., 2021).

Considering the activity in the construction sector and the need for materials for new projects, it is necessary to look at the practices that the WH prioritises in order to assess the potential for using secondary materials, with the recycling and reuse of construction materials being essential to creating a self-sufficient materials cycle (Schützenhofer et al., 2022). For example, with the aforementioned practice of deconstruction, it is possible to adopt a more sustainable approach when following the WH, as this practice makes it possible to separate materials and consider them in a hierarchical order (Bertino et al., 2021).

2.2.3. The Role of Reuse in Circular Practices

As mentioned above, reuse can be defined as any operation whereby products or components that are not waste are reused for the same purpose for which they were designed, and this practice is second in the WH priority order. Implementing this practice is considered one of the best ways to implement a CE perspective (Cai & Waldmann, 2019b; Nußholz et al., 2019; van den Berg et al., 2020).

Despite this being identified as one of the most important practices to prioritise, it can still be seen that the most widely used methods of waste management are recycling and energy recovery, although the practice of reuse has many benefits (Eberhardt et al., 2019). The practice of reuse has always proved to be a common method over the years, but after the 19th century, with the introduction of mass manufactured materials in the construction sector, this practice started to be used less and less, and one of the reasons for this happening may be due to the fact that materials containing concrete are not easily reused (Anastasiades et al., 2021a). Furthermore, during the life cycle of a building, the parties involved may change, which can lead to uncertainties about the circumstances in which materials from these buildings can be reused (Eberhardt et al., 2022).

However, compared to recycling, reuse is a more environmentally suitable alternative (Eberhardt et al., 2022; Rakhshan et al., 2020; Xia et al., 2020), because it avoids negative environmental impacts resulting from the production of new materials and requires less energy consumption (Akanbi et al., 2018; López Ruiz et al., 2020). Also, increasing the amount of material that is reused can reduce the costs associated with transporting and disposing of CDW and extend the life of a landfill (Umar et al., 2017). In addition, this practice also ends up

reducing CO_2 emissions and decreasing the amounts of CDW sent to landfills (Akinade et al., 2017).

Thus, in the context of the necessary management of CDW, the practice of reuse proves to be an essential path with benefits for the construction sector (Oliveira et al., 2021). It can also bring economic benefits through the creation of a market for reusable materials, which can be found at lower prices than new materials (European Commission, 2017). It is also important to note that the process of reusing building materials must be considered from the very beginning of the project, i.e. from the design phase (Condotta & Zatta, 2021). Also, to avoid the short life span of buildings due to rapid urbanisation, sustainable planning is needed to promote the reuse of buildings (B. Huang et al., 2018).

Therefore, this type of practice should be studied and, due to the lack of studies conducted and the lack of knowledge about the practice, it is more difficult to implement it in the construction sector, as the stakeholders do not have the necessary knowledge to use it (Rakhshan et al., 2020). There is also a need for reuse demonstration projects to raise awareness of the practice (Harris et al., 2023).

2.3. Regulatory Policies: A Closer Look at the European Union and Portugal

In order to carry out the study proposed in this dissertation, it is also essential to know the regulations implemented in the EU and in Portugal regarding waste management, as well as CDW management. Therefore, this chapter focuses on the analysis of the regulations and plans that have been implemented in this field of study since 2008, when one of the most relevant directives for EU waste management was created.

Therefore, the regulations are presented in order of implementation and divided into sub-chapters, one for the EU and the other for Portugal, as this is where the research took place. Figure 2.4 shows the chronological order of publication of these regulations implemented in the EU and also in Portugal.

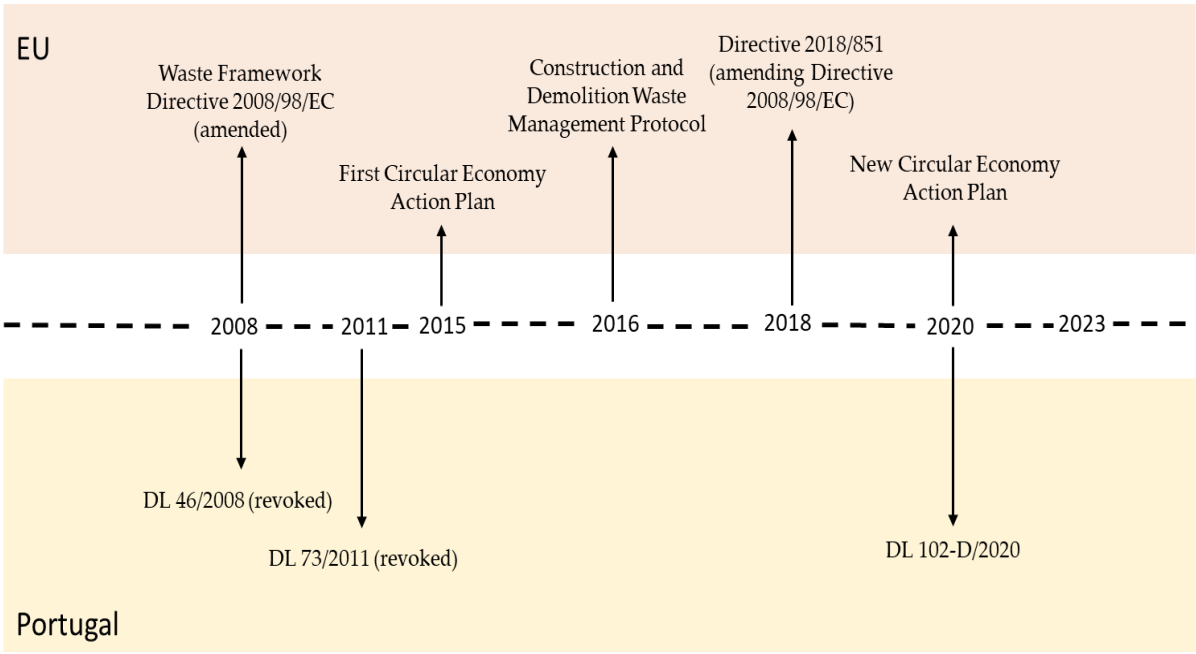

Figure 2.4. Chronological order of publication of EU and Portugal regulations

2.3.1. European Union Regulations

The EU regulations are very important to consider, as they are the basis for the practices used in the different countries belonging to the EU, as well as the policies created by each country. These regulations are presented below.

Waste Framework Directive (amended)

According to the European Commission, (2023), the Waste Framework Directive 2008/98/EC, of November 19th, in addition to defining some specific concepts of waste management already mentioned above, also defines some rules on how waste should be managed and carefully considered. This is how waste management should be considered: no impact on water, animals, air, soil or plants, no risk to the environment or human health, no impact through noise and odours, and without affecting the landscape and places of particular value.

The Directive also stipulates that the WH principle should be followed, that the competent national authorities should draw up waste management plans and waste prevention programmes and aim of achieve a minimum of 70% by weight by 2020 for preparation for reuse, recycling and other forms of material recovery, including filling operations using waste as a substitute for other materials, of non-hazardous construction and

demolition waste, with the exception of natural materials defined in category 17 05 04 (soils and stones not containing hazardous substances) of the European List of Waste.

The Waste Framework Directive was amended by the Directive (EU) 2018/851, of May 30th. In this new version, it is provided more specific information on the management of CDW and initiatives to adopt certain practices, which includes:

- Encourage the reuse and repair of building materials;
- Promote the reduction of waste generation in processes related to various sectors of activity, such as construction and demolition, by favouring best available techniques;
- Member States should take measures to promote the practice of selective demolition to enable the removal of hazardous substances and to facilitate reuse and recycling practices;
- Establishment of sorting systems for construction and demolition waste at least for wood, mineral fractions (concrete, bricks, tiles and ceramics, stones), metal, glass, plastic and plaster);
- Until 31 December 2024, the Commission shall consider the setting of preparing for re-use and recycling targets for construction and demolition waste and its material-specific fractions. To that end, the Commission shall submit a report to the European Parliament and to the Council, accompanied, if appropriate, by a legislative proposal;

Circular Economy Action Plan

The Circular Economy Action Plan was adopted by the European Commission in 2015 with the aim of improving the EU economy and creating more sustainable and competitively advantageous benefits. This plan, together with waste management legislation, also aimed to set targets to reduce landfill and improve preparations to increase the practice of recycling and reuse.

According to the European Commission, (2015), the Circular Economy Action Plan also focuses on the management of waste from various industries. It focuses on the most resource-intensive sectors where the potential for circularity is high: electronics and ICT, batteries and vehicles, packaging, plastics, textiles, construction and buildings, food, water and nutrients. This plan states that the European Commission intends to define several objectives

and guidelines, such as those related to demolition zones, in order to promote CDW management systems.

In 2020, the European Commission presented the new Circular Economy Action Plan (European Commission, 2020), which aims to take initiatives throughout the life cycle of products and introduce legislation and other measures to promote action in this area. The plan also focuses on implementing measures to increase circularity, for example in the construction sector. It also aims to take further measures to reduce the amount of waste produced and to create a market for high quality secondary materials (European Commission, 2020).

The new Circular Economy Action Plan also mentions that the European Commission has made a commitment to develop a new strategy for a sustainable built environment. This would aim to reduce climate impacts by improving material efficiency, CDW management, digitalisation and skills through various measures such as: encouraging the creation of initiatives to minimise soil sealing; promoting the sustainable and circular use of excavated soil and brownfield rehabilitation; promoting measures to increase the durability and adaptability of built assets according to a CE perspective for building design; and creating digital logbooks for buildings.

Construction and Demolition Waste Management Protocol

The Construction and Demolition Waste Management Protocol was implemented by the European Commission in 2016 with the aim of increasing the confidence in the CDW management process. According to the European Commission, (2016a) this will be achieved by:

- Improved waste identification;
- Source separation and collection;
- Improved waste logistics;
- Improved waste processing;
- Quality management;
- Appropriate policy and framework conditions;

The EU Protocol also emphasises the crucial role of reuse in sustainable waste management. It encourages EU countries to promote this practice in construction projects and specifies the need for high quality standards. The Protocol also recommends efficient sorting

and collection systems, as well as reliable certification procedures to ensure the quality of reused materials.

In addition, the Protocol provides a checklist to help workers in construction companies check whether projects have been managed properly to maximise the amount of reused and recycled materials. The checklist is divided into four main categories: waste identification, source separation and collection; waste logistics; waste processing and treatment; and quality management and assurance.

2.3.2. Portuguese Regulations

According to Antunes et al. (2021), in Portugal the level of action to promote circularity in the construction sector is still relatively low. There is still a certain lack of information on the activities of the construction sector, which leads to traditional practices, although the country has great potential to improve its level of sustainability in this sector. However, according to Augusto Mateus & Associados, (2017), one of the priority targets for the promotion of circularity in Portugal is the construction sector, and companies in Portugal show some interest in promoting innovation with environmental benefits, but there is still little motivation for circularity among companies.

Portuguese legislation on the circularity and management of CDW is presented below in chronological order.

Decree-Law no. 46/2008 of May 12th

Decree-Law no. 46/2008 of May 12th defined the activities related to the management of CDW, later amended by Decree-Law No. 73/2011 of June 17th, both of which were subsequently revoked by Decree-Law no. 102-D/2020 of December 10th, with subsequent amendments. This was one of the first regulatory instruments at European level, as a separate regulatory initiative focused on CDW. It focuses on the activities of collection, transport, storage, prevention and reuse, sorting, treatment, recovery and disposal.

In addition, this Decree-Law focused on promoting the minimisation of the production of CDW through the reuse of materials and the use of materials that are not likely to generate CDW containing hazardous substances. One of the practices implemented in the context of reuse is the reuse of uncontaminated soil and rock. Soil and rock that does not contain hazardous substances from construction activities must be reused in the original work of construction, reconstruction, extension, alteration, repair, conservation,

rehabilitation, cleaning and restoration, as well as in any other original work involving a construction process, abbreviated as original work.

Decree-Law no. 73/2011 of June 17th

As mentioned above, this Decree-Law amends Decree-Law No. 46/2008 of May 12th, which amended the general waste management regime and transposed the Waste Framework Directive 2008/98/EC. The Decree-Law no. 73/2011 of June 17th was later revoked by Decree-Law no. 102-D/2020 of December 10th. Thus, this Decree-Law defines some key concepts in the field of waste management in order to update the knowledge of the current needs in this field.

In addition, the Decree-Law focuses on promoting the importance of recycling practices in order to achieve the targets set, such as the use of at least 5% of recycled materials in public works contracts. Finally, as already mentioned, it transposes the Waste Framework Directive 2008/98/EC, with the aim of achieving a minimum of 70% by weight by 2020 for preparation for reuse, recycling and other forms of material recovery, including filling operations using waste as a substitute for other materials, of non-hazardous construction and demolition waste, with the exception of natural materials defined in category 17 05 04 of the European List of Waste.

Decree-Law no. 102-D/2020 of December 10th

Decree-Law no. 102-D/2020 of December 10th is responsible for approving the general waste management regime, which amends the regime for the management of specific waste streams by transposing several EU directives, such as the aforementioned Directive 2018/851 of the European Parliament and of the Council of May 30th.

According to this Decree-Law, the aim is to promote circularity initiatives and prioritise reusable products and sustainable, non-toxic reuse systems over single-use products. This incentive is intended to promote the reduction of the amount of waste produced. It also defines the procedures to be followed by industries in various economy sectors, such as the reuse of plastics.

In order to promote the practice of reuse, this Decree-Law stipulates that:

- The holder of the products must organise their storage and transport in such a way that the products are not unnecessarily damaged and that undamaged or

repairable products and their components are kept separate, if necessary, with a view to promoting the reuse of products and their components;

- The distributor of the product shall also organise the reception to avoid damage to the delivered products and comply with other provisions on storage and transport with the aim of promoting the re-use of products and their components;
- In order to promote reuse, the producer of the product shall ensure that the holders of the product can obtain the necessary information on the possibility of re-using the product and its components and on its dismantling, as well as information on the content in terms of substances of very high concern, available on the SCIP platform of the European Chemicals Agency;

Regarding the construction sector, this Decree-Law promotes practices that encourage selective demolition, which aims to apply the principles established in the WH. More specifically, it promotes practices that facilitate the deconstruction of buildings into more easily disassembled elements, such as window frames and water pipes, but also other materials. It also states that the final inspection and selective demolition plan for works subject to prior inspection must be provided for in the municipal urbanisation and building regulations. This easy dismantling of materials maximises the possibility of recycling and reuse, and it is mentioned that materials that cannot be reused and that constitute CDW must be sorted on site in order to be forwarded. Sorting of this type of waste must be ensured at least for wood, mineral fractions including concrete, bricks, tiles and ceramics, stone, metal, glass, plastics and gypsum.

In addition, it lists various practices that should be implemented on public and private construction sites, with some of these mentioned in relation to private sites: ensure that there is an appropriate packaging system on site that allows selective management of CDW; ensure that a CDW sorting method is applied on site or, if this is not possible, that it is sent to a licensed treatment operator; ensure that CDW is kept on site for the shortest time possible, in accordance with the principle of protecting human health and the environment. It also sets a target of using at least 10% recycled materials or materials containing recycled materials in relation to the total amount of raw materials used on the construction site. Furthermore, it

mentions a target to reduce the amount of non-urban waste per unit of GDP by 10% in 2030 compared to 2018, particularly in the construction and public works sector.

Regarding the management of CDW, the Decree-Law also stipulates that:

- It is the responsibility of all those involved in its life cycle, from the original product to the waste generated;
- If the CDW is produced in private premises that do not require a licence and are not subject to prior notification, its management is the responsibility of the entity in charge of municipal waste management;
- If it is not possible to identify the producer of the waste, the responsibility for its management lies with the holder;
- The responsibility of the entities referred to in the previous paragraphs is extinguished by the transfer of the waste to a licensed waste management operator or by its transfer, in accordance with the law, to the entities responsible for waste management systems;

2.4. Innovative Approaches for Promoting Reuse in the Construction Sector

In recent years, a number of methods have been developed to improve waste management and this area can benefit from a number of innovative technologies (Spišáková et al., 2022). It is therefore important for the scope of this study to be aware of these approaches in order to achieve the intended objectives. Some of these approaches are outlined below.

2.4.1. Building Information Modeling

The Building Information Modelling (BIM) is a technology that captures more and more interest for the benefits of its use for CDW management in a CE perspective (Charef & Emmitt, 2021). Another way of characterising BIM is that it is a digital representation of the physical characteristics of a building (Ahmed, 2018). This innovation is an object oriented model (Akbarieh et al., 2020), which empowers other new technological innovations, such as mobile applications and the automation of certain activities (Stojanovska-Georgievska et al., 2022). These new innovations that can be created through BIM also make it possible to fulfil certain

missing needs, for example in construction projects (Sanchez et al., 2021) and further assist stakeholders (Gordon et al., 2023; Ullah et al., 2019).

Thus, as expected, BIM is an innovation already being implemented in the construction sector over the last two decades that, consequently, allows to increase productivity and improve performance in this area (Stojanovska-Georgievska et al., 2022). It allows to visualise the information of all the material streams of a building (Leising et al., 2018b), so that any change to a material would be visualised automatically in all perspectives and also allows errors to be visualised in advance (Akbarieh et al., 2020). In addition to the benefits already mentioned, BIM can be used to assess different phases of a building's construction and even for the initial design phase (Ahmed, 2018). However, according to Nikmehr et al. (2021), most of the actions that can be carried out with BIM are carried out for the construction phase and the design phase, but there is not much research on the end-of-life phase, i.e. after the construction phase of the building is over.

Furthermore, according to Bertin et al. (2022) and Wijewickrama et al. (2021) digital building models such as BIM are crucial for promoting the reuse of construction materials. In order to practise reuse, stakeholders need to be aware of various aspects, such as the amount of materials that can be reused and the definition of the necessary measures prior to selective demolition of a building, among others, all of which can benefit from the use of BIM (Akbarieh et al., 2020; Wijewickrama et al., 2021; Xiao et al., 2023).

In addition, according to Xing et al. (2020), which studied the combination of cyber-physical information for online identification, inspection and exchange of reusable components with BIM and other technologies, the practice of reuse can become more accessible and the combination of different platforms with BIM can provide stakeholders with more critical information. This information includes maintenance records, physical conditions, and technical specifications, which can then be monitored by stakeholders. In addition, the author points out that the combination of the different technologies studied can allow designers to compare the suitability of different materials online and import certain components for reuse in new designs. It is also important to note that this type of technology needs to be further developed to overcome the challenges and to be integrated as a digital solution to promote sustainable practices such as reuse (Gordon et al., 2023).

This technology has been quite important for various industries on the planet (Ahmed, 2018) and, according to Ullah et al. (2019), the use of this innovation varies from country to

country, with its importance being emphasised in countries such as the United States, the United Kingdom and the Scandinavian countries.

2.4.2. Material Passport

Another innovation created is the material passport (MP), which is a way to promote CE (Luscuere, 2017). According to van Capelleveen et al. (2023), the concept of the material passport is a digital platform, consisting of a certified identity of a product, which allows access to the different records of the life cycle of this product, so that it is possible to know its circulation characteristics, as well as its value, and also the circular opportunities related to this product.

Although there have been several attempts to exploit this innovation, there is still a lack of awareness of the concept and it has not yet been fully implemented in the construction sector (Kedir et al., 2021). Furthermore, in the case of Portugal, for example, it was noted that there was still a lack of knowledge about this innovation on the part of municipal technicians (Ramos et al., 2023). This may be one of the reasons why the use of this innovation has not yet been fully implemented in the sector. However, it is an innovation that improves the phases of activity in the construction sector, providing information on the quantitative and qualitative characteristics of the building material, thus helping to improve the various design phases (Honic et al., 2019). Thus, the MP creates a transparency and safety factor for consumers (Adisorn et al., 2021). The MP also brings other benefits, such as getting different types of stakeholders to share information about materials and thereby increasing the circularity of the sector (X. Chen & Lu, 2017). The type of characteristics identified in the information on each material allow it to increase circularity at the end of its life cycle (Lu et al., 2023), reducing costs associated with the recovery of materials (Smeets et al., 2019), gaining for reuse (Honic et al., 2019), as well as recycling (Schaubroeck et al., 2022).

The MP is a kind of tool that promotes and maximises reuse potential (Smart Waste Portugal, 2021). According to Smeets et al. (2019), when it comes to using passport materials to increase the practice of reuse, there are many benefits, such as sourcing advantages and lower costs due to the use of the MP, which eliminates the need for certain tests on materials and certain reconditioning activities. In addition, according to Giorgi et al., (2022), several stakeholders believe that the MP can act as a response to the information requirements on a construction material, which in turn increases the chances that these materials will be

recovered and reused and can contribute to the implementation of a platform of information on construction materials that promotes large-scale flow management and monitoring.

An example of a project that developed a MP was carried out in Portugal by the National Laboratory of Energy and Geology (LNEG), where the project (De)construct for the Circular Economy took place. According to LNEG, (2022), this was carried out with the aim of creating a regional strategy to promote circularity through the recycling and reuse of CDW, in order to prevent construction materials from becoming waste and thus minimise the environmental impact of the construction sector. This MP is designed to provide information about the product or building throughout its life cycle, which in turn allows it to differentiate itself from the competition through transparent communication about the characteristics of each product as well as its circularity potential. In addition, this innovation aims to promote knowledge for companies in the sector so that they have a more active understanding of their products, which in turn promotes the development of more efficient solutions throughout the whole life cycle of the product. This MP model was developed and consists of a *Microsoft Excel* document with eight spreadsheets, each of which allows to add different information about the product and its characteristics.

2.4.3. Pre-demolition Audits

Pre-demolition audits are tools to increase the recovery of construction materials through a CE perspective and implementation (Nováková et al., 2021). According to the European Commission (2016), which presented the EU Protocol on Construction and Demolition Waste Management, a pre-demolition audit should be carried out prior to any renovation or demolition work, which will help to identify the amount of CDW generated by the site and help to implement a correct method of dismantling. The aim of these audits is to increase information on material flows and thus reduce the amount of wasted materials by using the materials in other ways, such as recycling and reuse (Rašković et al., 2020).

In addition, conducting a pre-demolition audit, helps improve worker safety and helps stakeholders define site-specific waste management plans (García et al., 2017), increasing recovered material (Rašković et al., 2020) and, consequently, increasing the profit (European Commission, 2016a). In addition to the benefits already mentioned regarding the safety of workers on site, it is important to note that this type of audit is also very useful in assessing the presence of hazardous materials, which are the first to be safely removed from

the site so as not to affect other types of materials that can be recovered (Wahlström et al., 2019).

One of the examples where this type of approach has been studied is in Portugal, where the National Civil Engineering Laboratory (LNEC), the Portuguese Environmental Agency and the Institute of Public Markets for Real Estate and Construction carried out the CLOSER - Close to Resources Recovery project, with the aim of promoting the principles of CE in the construction sector. As part of this project, it was developed a guide for pre-demolition audits. According to LNEC, (2021), the aim of these audits is to recover materials and CDW by implementing a more appropriate methodology that also allows construction materials to be sent to the most suitable destinations. It also lists various objectives for carrying out these audits, some of which have already been mentioned, and others such as: improving the quality of the CDW produced, identifying recommended destinations for materials and improving compatibility between planned and actual material flows. In addition, this guide mentions several essential audit phases, such as the documentation study and the *in situ* study. The documentation study refers to the study of information that allows a detailed planning of the site visit, based on a preliminary survey of materials, where various information is gathered, such as the age of the building, the type of structure and the waste management operators in the surrounding area. The *in situ* study confirms the information contained in the documentation study and inspects the site, highlighting the need for testing, verifying the condition of the materials, signalling reusable materials and defining the equipment needed for evaluations during subsequent visits. However, there is still a lack of knowledge about this practice (Ramos et al., 2023).

Regarding EU countries, according to the European Commission, (2017), several countries have already included this practice in their legislation. However, the application of this practice is still limited and may be only voluntary (mentioned in waste management plans), regionally regulated or limited to hazardous waste. These countries are Austria, Belgium, Bulgaria, Czech Republic, Finland, France, Hungary, Ireland, Italy, Luxembourg, Malta, Poland, Slovenia, Spain, Sweden and the Netherlands.

Therefore, pre-demolition audits should be part of all projects in the construction sector related to renovation and demolition, and although recommended, should also be mandatory, with the benefit of increasing the recovery of materials through the implementation of this type of audit (Spišáková et al., 2021).

3. METHODOLOGY

3.1. Methodology Purpose and Objectives

The methodology used for the study of this dissertation aimed to understand several aspects related to the practice of reuse of construction materials, particularly in the EU Member States. It also focused on understanding the relationship between the implementation of these practices and the regulations that have been adopted over the years in EU countries, such as the European Commission Waste Framework Directive 2008/98/EC, the European Union Directive 2018/851 of the European Parliament and of the Council of May 30th which amended the latter, and the Circular Economy Action Plan.

3.2. Research Questions

Thus, in order to carry out the intended study and reach conclusions, a group of key questions were defined:

- How has research on material reuse in the construction sector been influenced by the implementation of European Union legislation since the Waste Framework Directive 2008/98/EC?
- What are the themes and trends most addressed by researchers and published in the scientific literature?
- What are the main advantages and the main barriers identified by the authors?
- How researchers use the concept of reuse?
- Is there a relationship between European policies and strategies and research on reuse of building materials?
- What factors do the authors identify as necessary to promote reuse of materials in the construction sector?

3.3. Systematic Literature Review

In order to answer such questions and address this issue, the following research was conducted through a Systematic Literature Review (SLR). This type of method contrasts with classical literature reviews because it follows a replicable, scientific and transparent approach. It also helps to gather any relevant papers that meet the pre-defined criteria to provide information to answer a particular research question (Mengist et al., 2020).

The scheme representing the process is shown in Figure 3.1. To carry out the SLR, three search engines were initially used, namely Scopus, Web of Science and B-on. These three were chosen because each platform provides a wide range of results. Taken together, they therefore provide a richer set of results, which increases the robustness and rigour of the search conducted and the results obtained, as well as reducing the likelihood of omitting articles relevant to the study.

In these search engines, a search was conducted using pre-selected Boolean expressions to find articles that focused on waste management and mainly on the topic of reuse. In this way, the following expressions were selected: "reuse" AND "construction and demolition waste" OR "CDW" OR "C&DW" OR "construction material*" OR "construction components" OR "material passport" OR "Building Information Modelling" OR "BIM" OR "deconstruction" OR "selective demolition".

The use of the term "AND" allows the results to include articles that contain the term "reuse" in combination with the second term. Furthermore, the use of the "OR" expression allows different sets of expressions to be expressed in the results. Finally, the example of the "*" in the expression "building material*" allows the search to include not only the singular but also the plural form of the word "material".

The term "construction and demolition waste" was chosen, although it is not the most directly related to the topic of reuse, as it refers to waste and not to construction materials. This choice was made because during the selection of search limitations in the search engines, it was noticed that this term provided search results that were much more related to the topic under study. In addition, the terms "CDW" and "C&DW" were used as these are the most commonly used acronyms to refer to construction and demolition waste. This reduced the risk of omitting elements relevant to this study.

The terms "material passport" and "Building Information Modelling" were also chosen because they are some of the innovative methods that help to implement the practice

of reuse. For this reason, it was important to use such terms so that it would be possible to find papers related to these types of methods that are directly related to the practice of reuse. The term "BIM" was also used, as this is the most commonly used acronym to refer to Building Information Modelling.

The choice of the terms "construction material*" and "construction components" was intended to show results directly related to construction processes, since when discussing reuse it is directly related to these terms, since it is the materials and components that can ultimately be used for reuse. Thus, by using both terms, the search is able to cover all types of construction elements that can be used in this practice.

The terms "deconstruction" and "selective demolition" are used because they are sustainable practices associated with the practice of reuse. Both terms refer to the same process, but they are two different ways of referring to it, so the two terms were chosen so as to avoid omitting articles that might be relevant to the study, as both terms refer to a practice that is in line with a CE perspective.

In addition to the defined terms, the search was restricted to the content of the titles, abstracts, and keywords. A time period was also defined for the publication of the articles, namely from 2008 to the present day. This period was defined due to the fact that the European Commission Waste Framework Directive 2008/98/EC, of November 19th was published during this year. This Directive was an important step forward as it set targets for the regulatory management of CDW and the establishment of strategies for the management of this specific waste stream, guiding EU countries towards a more sustainable approach to the management of this type of waste from a CE perspective. In turn, Directive 2018/851, of May 30th has brought an even more focused vision to this area. Other restrictions that were applied and that limited the research were the exclusive use of the English language and the limitation of the results to articles from countries that are members of the EU, given that this study focuses on this area and the regulations implemented in it.

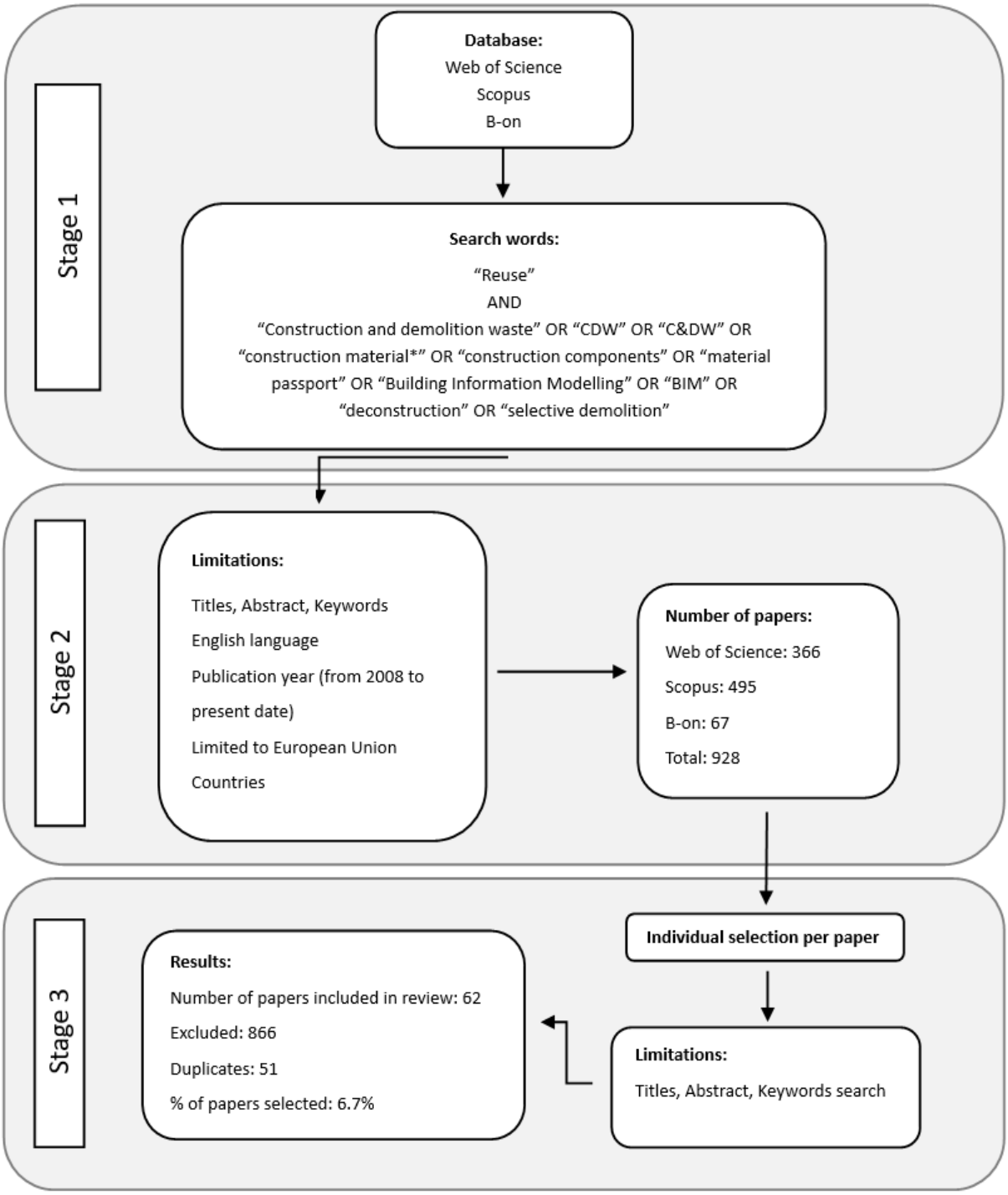

Figure 3.1. Systematic Literature Review Framework

Once the search and its limitations had produced a large number of results, a process of exclusion was carried out. Articles were excluded by reading the titles and abstracts of the articles resulting from the initial search, and in some cases by reading the introduction and the methodology of some articles to see if they were relevant to the study being conducted.

This process excluded a large number of articles so that only articles within the focus area were selected.

Excluded articles include fields of study such as medicine, biology, pharmacology, environmental science articles focused on other types of reuse studies such as water reuse and articles focused on recycled aggregates. In addition, articles related to specific computer technologies or articles that focused exclusively on technological practices in the operation of BIM were excluded, as in this case the topics did not fit the scope of this study.

3.4. Data Analysis and Categorisation

Once the SLR had been used to select the articles needed to answer the key questions defined, it was necessary to find a method to analyse the articles in order to be able to answer the mentioned questions.

In order to organise the information, it was important to divide it into categories. This categorisation had several advantages, such as the possibility of looking at aggregated information about the articles, which allowed different conclusions to be drawn. For this purpose, *Microsoft Excel* was used as the main tool for the analysis.

In this way, the categorisation was carried out according to several categories, which in turn led to concrete conclusions that will be discussed later. Here are the categories that were in place:

- Article publication year: to analyse the evolution of the number of articles published per year since the publication of the European Commission Waste Framework Directive 2008/98/EC, of November 19th;
- The affiliation of the published article: as the selection of articles was limited to the EU. This made it possible to assess which countries had published the most articles investigating CDW management and practices;
- A category was created to assess whether the papers referred to EU regulations published in recent years, and a second category was created to assess, among those that did, whether they mentioned the European Commission's Waste Framework Directive 2008/98/EC, the Directive 2018/851 and the Circular Economy Action Plan;
- A category related to the focus of the study, more specifically whether or not it focused exclusively on the study of reuse. This is because, although the selected articles were chosen with the intention of focusing on this area, since they were

selected only by the content of the titles, abstracts and keywords, sometimes, despite these referring to reuse, they end up not focusing on the practice. This category was quantitatively scored using a 3-points ordinal scale: "1" refers to articles that partially focused on reuse without applying it in the results and discussion, "2" to articles that did not focus exclusively on the practice, but mentioned its importance throughout the text and ended up talking about its importance, and "3" to articles that focused exclusively on the study of this practice;

- Another selected category focuses on whether articles correctly or incorrectly mention the concept of reuse as defined in the Waste Framework Directive 2008/98/EC, of November 19th. The aim of this category was to investigate whether this concept is still poorly mentioned in CDW management studies and to understand what types of errors are more common. Again, a sub-category using a 3-points ordinal scale was added to this category. In this way, "1" was used for articles that did not use the concept of reuse correctly, "2" for articles that used the concept well in several parts of the article but also contained some errors in the concept, and "3" for articles that used the concept of reuse correctly;
- The general theme addressed by the article;
- The type of methodology used in each study;
- The list of journals and publishers that published the articles;
- The geographical area in the specific case of case study articles;

This type of treatment of the results, as well as the categorisation mentioned, was relevant to organise the information intended to be studied and discussed in the following chapter where the results will be presented.

4. RESULTS AND DISCUSSION

Through the application of an SLR methodology, initial general results are presented and discussed, followed by a discussion that are focused on the research questions defined earlier. Lastly, a critical analysis of the results discussed is presented.

4.1. Research Overview

This subchapter first presents the results concerning the number of articles selected in the SLR as well as their identification according to author and year of publication. Subsequently, the results concerning the evolution of the number of articles published per year since 2008, the geographic distribution of articles published in the EU, the distribution of articles published by type of journal and publisher, and the current state of the EU waste management activities and how countries referred in the selected articles are addressing the CDW challenge are also presented in subchapters.

4.1.1. Article Selection and Identification

After performing the SLR, 62 articles were selected from the 928 articles found in the three search tools used. This corresponds to a total of 866 excluded articles, of which 51 were identified as duplicates. This resulted in a final article selection rate of 6.7%.

The 62 articles selected are presented and identified in Table 4.1 below.

Table 4.1. Identification of selected articles per year of publication

Publication date	Authors
2010	Del Río Merino et al. (2010); Couto & Couto (2010);
2011	Coronado et al. (2011); Marrero et al. (2011);
2012	Coelho & De Brito (2012);
2014	Silvestre et al. (2014); Pongiglione & Calderini (2014); Calvo et al. (2014);
2016	Coelho (2016);
2017	Sakaguchi et al. (2017); Kelly & Dowd (2017);
2018	Menegaki & Damigos (2018); Mangialardo & Micelli (2018); Ghisellini et al. (2018); Kanters (2018);
2019	Mihai (2019); Nußholz et al. (2019); Klinge et al. (2019); Hradil et al. (2019); Ruggeri et al. (2019); Bertin et al. (2019); Cai & Waldmann (2019b);
2020	Luciano et al. (2020); Akbarieh et al. (2020); Vares et al. (2020); Nußholz et al. (2020); van den Berg et al. (2020);
2021	Niu et al. (2021); Ottosen et al. (2021); Bertino et al. (2021); Whittaker et al. (2021); Nováková et al. (2021); Condotta & Zatta (2021); Antunes et al. (2021); Trtílek & Hanák (2021); van den Berg et al. (2021); Honic et al. (2021); Anastasiades et al. (2021a);
2022	Mrad & Frölén Ribeiro (2022); Spišáková et al. (2022); Banias et al. (2022); Andersson & Buser (2022); Marinho et al. (2022); Almeida et al. (2022); Al-Obaidy et al. (2022); Schützenhofer et al. (2022); Christensen et al. (2022); Freire-González et al. (2022); Schaubroeck et al. (2022); Karanafti et al. (2022); Etienne et al. (2022); Charlotte et al. (2022); Nemeth et al. (2022); Bertin et al. (2022); Quéheille et al. (2022); Besana & Tirelli (2022); Andersen et al. (2022);
2023	Anastasiades et al. (2023); Harris et al. (2023); Gordon et al. (2023); Honic et al. (2023); Derikvand & Fink (2023);

4.1.2. Publication Trends

The first results to be discussed in this study concern the trends that can be observed in the evolution of the number of publications over the years. Evaluating these trends makes it possible to draw the relevant conclusions about how research in the field studied has been developing. The selected articles in the SLR are presented in a time frame that goes from 2008 to the present, i.e. 2023. The graph relating to the number of articles published per year is shown in Figure 4.1.

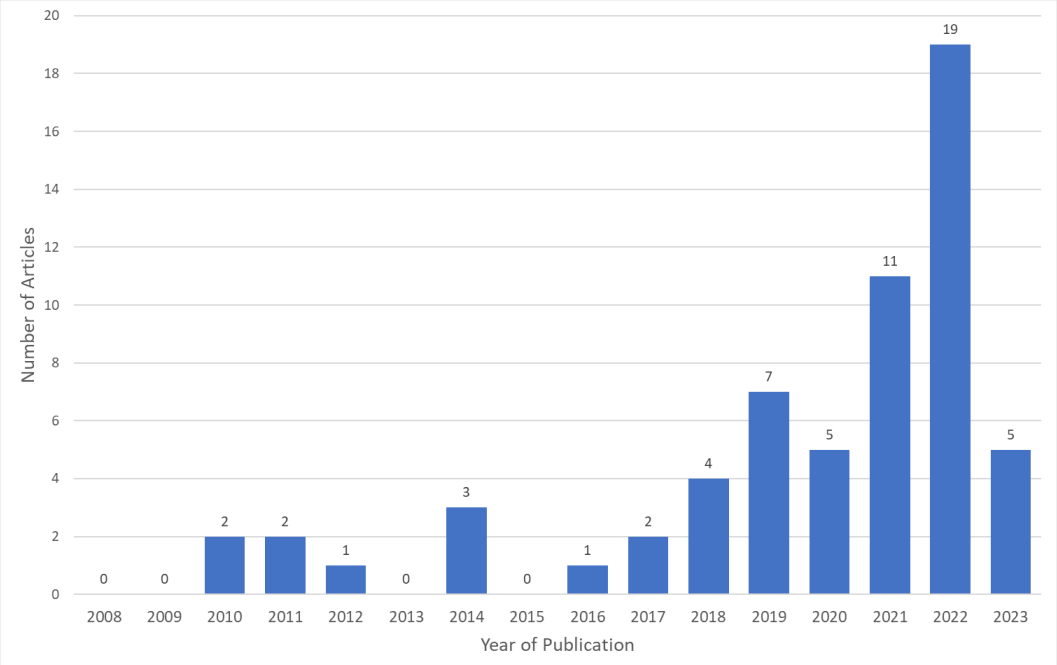

Figure 4.1. Number of articles published per year

When analysing the graphic of publication trends, it is possible to see some years in which no publications were identified, which may indicate a lack of research in this area during this period. However, it can be noted that after 2009, in 2010 and 2011, and also in 2017, two articles were published per year, which may indicate an increase in research awareness in this area. There is also a clear increase in 2014, with three publications in that year, between two years already mentioned as years with no publications.

It can also be seen that after 2015, an increase in the number of publications per year can be observed until 2022, with the exception of 2020, which shows a decrease in the number of publications. This decrease in publications in 2020 may indicate that the COVID 19 pandemic

has had an impact on research in this area. The increase is notably observed in 2021 and 2022, with eleven and nineteen publications per year respectively. This may indicate that, since 2016, there has been a greater effort and need to carry out research in this area. This new effort may also be related to new waste management problems and new regulations, such as the Waste Framework Directive, the Circular Economy Action Plan and the Directive 2018/851. It can also be seen that the increase in the number of articles published occurs between two and four years after the publication of these directives and policies.

It is also important to note that although 2023 also shows only five publications, in reality this year refers to the current period, so there may be several articles still in the process of being published.

4.1.3. Geographic Distribution

In order to understand which countries have carried out research in the field under study, the geographical distribution of the selected articles was analysed according to the affiliation of the authors. This type of analysis is useful for understanding the overall contribution of EU countries to the study of this topic. Figure 4.2 shows the distribution of the number of articles published by country.

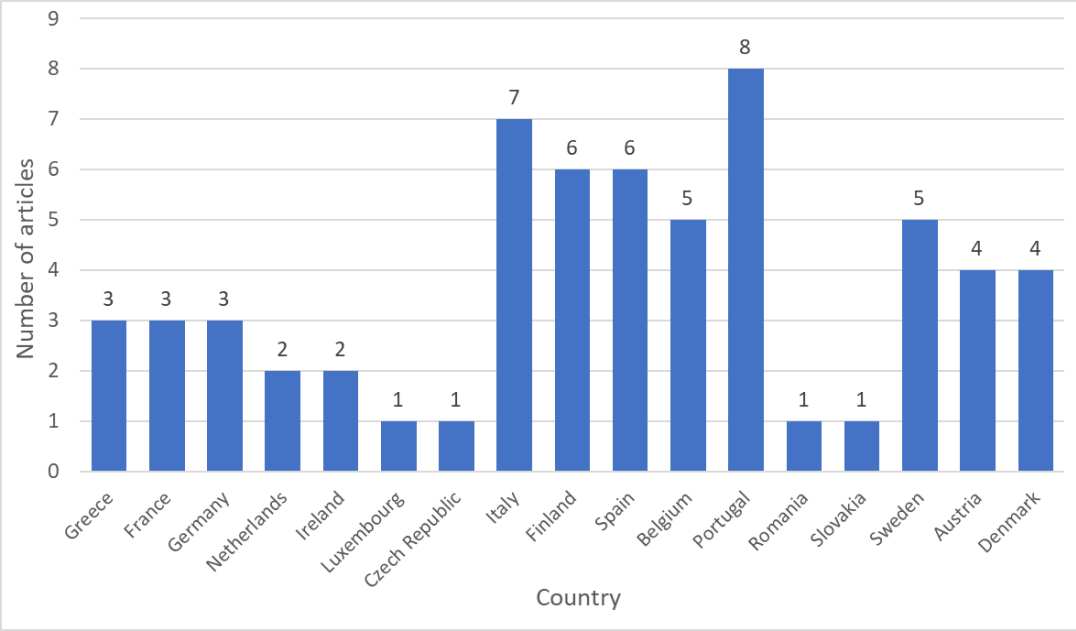

Figure 4.2. Number of publications by country

When analysing the chart with the geographic distribution, it is possible to see a distinction between countries with few publications, i.e. with little focus on research in the area under study, and countries with a higher number of publications, i.e. with more focus on research in this area.

First of all, it is important to note that Portugal stands out from the other countries with a total of eight articles published, which may reflect an effort to study and improve its practices. Italy, Finland and Spain stand out with seven (Italy) and six (Finland and Spain) published articles per country. Just below these countries are Belgium and Sweden with five published articles and Austria and Denmark with four published articles. There are also a number of countries that carry out research in this area, but which do not seem to be very focused on the subject in terms of the number of articles, such as the Czech Republic, Luxembourg, Romania and Slovakia, which have only one published article each.

According to the European Commission, (2017), which published the Resource Efficient Use of Mixed Wastes Improving Management of Construction and Demolition Waste Report, countries in the EU have transposed the Waste Framework Directive into their national legislation, which shows that there is some awareness and common principles for waste management. However, the report also states that not all countries have implemented the measures related to the Directive in the same way. Nevertheless, the differences in the number of publications per country mentioned above may be justified for this reason.

The report also categorises which countries still have developing, advanced or mature legislation on CDW management. For example, Romania and Slovakia are in the developing legislation group, so it makes sense that these countries have fewer published articles. However, Luxembourg and the Czech Republic, despite having few publications, are in the mature legislation and advanced legislation groups respectively. Portugal, Italy and Spain are in the advanced legislation group and Austria, Belgium, Denmark, Finland and Sweden are in the mature legislation group, so it makes sense that these countries have more articles published. Finally, countries such as Slovenia, Bulgaria, Croatia, Latvia, Poland and Lithuania are in the group with developing legislation, which may explain why no articles have been found on these countries.

In addition, it is possible to identify separately in some countries an evolution in the number of articles published over the period defined for the research. These countries are Portugal, Denmark, France and Greece.

Regarding Portugal, which, as already mentioned, has the highest number of published articles, the trend started in 2010 with one published article and remained constant in 2012, 2014, 2016 and 2021 until 2022, when the number of publications increased to three. The interest in the study of the field in question may be linked to the publication of Decree-Law no. 46/2008 of May 12th, which has since been revoked. The increase in 2022 may also be linked to the publication of the Decree-Law no. 102-D/2020 of December 10th. As for the remaining countries, the first year of publication of articles is relatively later than in Portugal. In Denmark, one article was published in 2021 and the number of publications increased to three in 2022. In the case of France, the first publication was in 2019, followed by two articles in 2022. Finally, for Greece, the first article was published in 2018 and two articles in 2022.

The difference in the number of articles published between countries may also be related to the fact that there are authors who are focused in this area of research and have published more than one article among the articles selected for the study. This analysis can be seen in Table 4.2. It was noted that for Portugal and France there are already authors who have published more than one article. In the case of France, two articles by the same author were published in 2019, (Bertin et al., 2019, 2022). In the case of Portugal, two articles by the same author were published in 2012, (Coelho & De Brito, 2012, and Coelho, 2016).

With regard to the remaining countries (i.e. those that have not shown an increase in publications over the years), there are still four that have authors who have published more than one article among the articles selected for the study, namely Belgium, Austria, Sweden and the Netherlands. In the case of Belgium, two articles were published by the same author in 2021, (Anastasiades et al., 2021a, 2023). Austria also had two articles published in 2021, (Honic et al., 2021, 2023). The same for Sweden, with one article published in 2019 and one in 2020 (Nußholz et al., 2019, 2020). Finally, the Netherlands also had two articles published by the same author in 2020 (van den Berg et al., 2020, 2021).

Table 4.2. Number of publications per author and per country

Country	Author	Number of Publications	Total
Sweden	Kanters (2018);	1	5
	Andersson & Buser (2022);	1	
	Harris et al. (2023);	1	
	Nußholz et al. (2019); Nußholz et al. (2020);	**2**	
Spain	Del Río Merino et al. (2010);	1	6

Country	Author	Number of Publications	Total
	Coronado et al. (2011);	1	
	Marrero et al. (2011);	1	
	Calvo et al. (2014);	1	
	Freire-González et al. (2022);	1	
	Gordon et al. (2023);	1	
Slovakia	Spišáková et al. (2022);	1	1
Romania	Mihai (2019);	1	1
Portugal	Couto & Couto (2010);	1	8
	Silvestre et al. (2014);	1	
	Coelho & De Brito (2012); Coelho (2016);	**2**	
	Antunes et al. (2021);	1	
	Marinho et al. (2022);	1	
	Mrad & Frölén Ribeiro (2022);	1	
	Almeida et al. (2022);	1	
Netherlands	van den Berg et al. (2020); van den Berg et al. (2021);	**2**	2
Luxembourg	Akbarieh et al. (2020);	1	1
Italy	Pongiglione & Calderini (2014);	1	7
	Mangialardo & Micelli (2018);	1	
	Ghisellini et al. (2018);	1	
	Ruggeri et al. (2019);	1	
	Luciano et al. (2020);	1	
	Condotta & Zatta (2021);	1	
	Besana & Tirelli (2022);	1	
Ireland	Kelly & Dowd (2017);	1	2
	Whittaker et al. (2021);	1	
Greece	Menegaki & Damigos (2018);	1	3
	Karanafti et al. (2022);	1	
	Banias et al. (2022);	1	
Germany	Cai & Waldmann (2019b);	1	3
	Klinge et al. (2019);	1	
	Nemeth et al. (2022);	1	
France	Bertin et al. (2019); Bertin et al. (2022);	**2**	3
	Quéheille et al. (2022);	1	
Finland	Sakaguchi et al. (2017);	1	6
	Hradil et al. (2019);	1	
	Vares et al. (2020);	1	
	Nováková et al. (2021);	1	
	Niu et al. (2021);	1	

Country	Author	Number of Publications	Total
	Derikvand & Fink (2023);	1	
Denmark	Ottosen et al. (2021);	1	4
	Charlotte et al. (2022);	1	
	Christensen et al. (2022);	1	
	Andersen et al. (2022);	1	
Czech Republic	Trtílek & Hanák (2021);	1	1
Belgium	Al-Obaidy et al. (2022);	1	5
	Anastasiades et al. (2021a); Anastasiades et al. (2023);	**2**	
	Etienne et al. (2022);	1	
	Schaubroeck et al. (2022);	1	
Austria	Bertino et al. (2021);	1	4
	Honic et al. (2021); Honic et al. (2023);	**2**	
	Schützenhofer et al. (2022);	1	

4.1.4. Journal Distribution

The following chapter aims to analyse the distribution of journals that publish in the field under study. By analysing this type of information, it is possible to identify the most relevant journals for this type of research. When carrying out a study in a particular field, it can be important to know the journals that publish in the required area, and the selection of journals can also have an influence on the results of the research. Table 4.2 shows the distribution of journals according to the number of articles selected and according to publisher.

Table 4.3. Distribution of articles according to journal and according to publisher

Publisher	Journal	Articles
Elsevier	Journal of Cleaner Production	Silvestre et al. (2014); Coelho (2016); Ghisellini et al. (2018); Nußholz et al. (2020); van den Berg et al. (2020); Honic et al. (2021); Condotta & Zatta (2021); Anastasiades et al. (2021a); Bertin et al. (2022); Quéheille et al. (2022);
	Resources, Conservation and Recycling	Pongiglione & Calderini (2014); Nußholz et al. (2019); Niu et al. (2021); Andersen et al. (2022); Christensen et al. (2022); Harris et al. (2023);
	Waste Management	Coelho & De Brito (2012); Freire-González et al. (2022);
	Current Opinion in Green and Sustainable Chemistry	Menegaki & Damigos (2018);

Publisher	Journal	Articles
	Developments in the Built Environment	Honic et al. (2023);
	Automation in Construction	Gordon et al. (2023);
MDPI	Sustainability	Couto & Couto (2010); Calvo et al. (2014); Mihai (2019); Akbarieh et al. (2020); Antunes et al. (2021); Banias et al. (2022); Almeida et al. (2022); Al-Obaidy et al. (2022); Schützenhofer et al. (2022); Mrad & Frölén Ribeiro (2022); (Besana & Tirelli (2022);
	Applied Sciences	Bertino et al. (2021); Spišáková et al. (2022);
	Buildings	Kanters (2018); Derikvand & Fink (2023);
IOP Publishing	IOP Conference Series: Earth and Environmental Science	Ruggeri et al. (2019); Bertin et al. (2019); Klinge et al. (2019); Trtílek & Hanák (2021); Schaubroeck et al. (2022); Karanafti et al. (2022); Etienne et al. (2022); Charlotte et al. (2022); Nemeth et al. (2022);
Taylor & Francis	Structure and Infrastructure Engineering	Vares et al. (2020);
	Construction Management and Economics	van den Berg et al. (2021); Andersson & Buser (2022);
	Advances in Building Energy Research	Whittaker et al. (2021);
	International Wood Products Journal	Sakaguchi et al. (2017);
	Journal of Civil Engineering and Management	Marinho et al. (2022);
Springer	Clean Technologies and Environmental Policy	Cai & Waldmann (2019b);
	Waste and Biomass Valorization	Coronado et al. (2011); Luciano et al. (2020);
	Smart and Sustainable Planning for Cities and Regions	Mangialardo & Micelli (2018);
SAGE Publishing	Waste Management & Research	Del Río Merino et al. (2010); Anastasiades et al. (2023);
Bentham Science Publishers	Open Construction and Building Technology Journal	Marrero et al. (2011);
John Wiley & Sons	Steel Construction: Design and Research	Hradil et al. (2019);
ICE Publishing	Waste and Resource Management	Kelly & Dowd (2017);
Sciendo	Nordic Concrete Research	Nováková et al. (2021);
CISA Publisher	Detritus - Journal for waste resources & residues	Ottosen et al. (2021);

As can be seen, there is still a relatively large variety of journal types in the area under study. However, it can be observed that many of the journals presented only refer to one or two published articles.

However, four journals stand out with a higher number of articles published. These are the Resources, Conservation and Recycling with six published articles, the Journal of Cleaner

Production with ten published articles, the IOP Conference Series: Earth and Environmental Science with nine articles and Sustainability with eleven articles. The latter is the journal with the highest number of published articles among all the journals examined regarding the articles selected for the study.

It can also be seen that the publishers responsible for the most articles are Elsevier with twenty one articles, the Multidisciplinary Digital Publishing Institute (MDPI) with fifteen articles, IOP Publishing with nine articles, Taylor & Francis with six articles and Springer with four articles.

4.1.5. Current State of European Union Waste Management Activities and How Countries are Addressing the CDW Challenge

As it has already been possible to conclude, the implementation of a CE perspective in the construction sector is essential to diminish the impacts that it presents, so the countries belonging to the EU have already started to take some measures. This chapter focuses on presenting information on the measures taken by some EU countries, considering the relevant information found in the selected articles of the SLR. In this way, this chapter aims to provide a more comprehensive understanding of the countries mentioned in the articles under review, which will be used to answer the key questions. According to Mrad & Frölén Ribeiro, (2022), a closer look at the publications in the construction sector reveals that only about 10% of the studies in Europe deal with CE in this sector.

Introducing the Czech Republic as a first case, this country is already starting to show some awareness and some more sustainable practices in the construction sector. According to Trtílek & Hanák, (2021), which carried out surveys to better understand the evolution of environmental performance in the construction sector in this country, most companies are already aware of the need to practise more sustainable practices, showing an evolution in environmental responsibility. However, only about one third of companies still carry out assessments according to environmental criteria. This factor may mean that the country's strategies are not yet fully adapted and, as a result, stakeholders are not yet fully promoting the need for practices that are higher on the waste hierarchy, such as reuse. In addition, according to this study, information sharing and systems should be promoted for these companies to start implementing measure systems for environmental responsibility.

On the other hand, it was possible to realise through the articles that there are still countries such as Romania, which still have relatively poor issues regarding their waste management, with a large fraction of CDW management situations, such as illegal dumping. According to Mihai, (2019), who carried out a study on the state of waste management in Romania, the country still has poor waste management. Companies in the construction sector are responsible for transporting the CDW they produce to disposal sites. However, CDW management is still quite inadequate, especially in smaller towns, which means that there is still a relative amount of illegal disposal, and it is essential to strengthen measures and regulations in this area. Once again, as in the case of the Czech Republic, this may mean that the country's regulations still need to be adapted to prioritise more sustainable waste management practices, such as the promotion of reuse.

This problem of illegal dumping of CDW due to poor waste management in the countries of EU is mentioned in several of the selected articles, for example, this is a problem that has already been quite referenced in Spain. Spain, due to a large activity in the construction sector and the production of a large volume of CDW, has caused some negative impacts on the environment as is the case of pollution of aquifers (Marrero et al., 2011), and started to define measures to make stakeholders find ways to manage the CDW they produced. This was because the country had problems with a lack of infrastructure for CDW valorisation, such as recycling facilities (Calvo et al., 2014; Coronado et al., 2011). As there are still problems in promoting recycling, this could mean that practices that are even higher on the WH priority list, such as reuse, don't get the proper attention required.

It is also mentioned in an article by Banias et al. (2022) who carried out a study on alternative strategies for waste management in the construction sector, that in Greece, until recently, the activities of the construction sector depended on the initiative and willingness of those involved, and that there is still a certain amount of illegal dumping, as well as the lack of a system for collecting construction materials to prevent them from becoming waste. However, the author also mentions that some building materials, such as windows and doors, are often reused. It is also stated that there is a lack of data on the statistics of CDW produced in the country (Karachaliou & Paralika, 2019), which makes it difficult to assess the state of this management. This lack of data may also mean that these statistical systems for measuring waste generated are still developing, so there may not yet be enough data to properly assess the amount of materials being sent for reuse.

In the case of Portugal, according to Marinho et al. (2022), both recycling and reuse practices are not yet common practices and, according to the interviews conducted, only 6% of the respondents indicated that they use the practice of reuse in their construction activities. In this way, it is also concluded that there are still large quantities of CDW that have to be disposed of in landfills, in addition to the fact that, despite the mandatory sorting on construction sites, respondents point to problems related to the fact that this type of activity leads to high costs to carry out.

According to Nováková et al. (2021), which carried out a study on current regulations and practices in the arctic region, it can be concluded that some countries are also more advanced in terms of environmental responsibility in construction waste management, such as Finland, which follows the Waste Framework Directive. According to this study, Finland has already achieved the target of recycling 70% of CDW by weight and has also managed to ensure that only contaminated CDW is sent to landfill, thanks to the implementation of a number of company practices and the fact that some companies sell some construction materials from the sector's activities.

As for other Nordic countries, such as Denmark, there are also several companies that are already implementing a CE methodology. According to Ottosen et al. (2021), who conducted a study on the current state in Denmark through interviews with several companies, those who already are with a CE perspective, have begun to implement this vision due to the fact that they have also begun to see this as a business opportunity. Through these interviews, the authors also realised that the construction sector in this country is aware of environmental responsibilities and that, in addition, many stakeholders share an interest in improving their practices towards more sustainable practices. However, some of these stakeholders still fear that building owners may put financial benefits above environmental responsibilities.

Finally, in Sweden, its waste management legislation has also been based on and is guided by the Waste Framework Directive, with the aim of reducing the amount of waste produced and preparing waste for more sustainable practices (Andersson & Buser, 2022). However, according to Andersson & Buser, (2022), who conducted research involving interviews with construction companies, found that contracts with contractors are mostly vague when it comes to waste management specifications, with general statements. Despite this, it is mentioned that the companies interviewed work together to share knowledge on practices such as recycling, and that stakeholders in these companies are also interested in

and attend conferences on CDW management. It is also important to add that some companies even provide training in this area, for example through meetings with employees from different areas within the company to share the necessary knowledge in this field, and project managers also hold meetings to share with subcontractors the regulations they follow regarding waste management.

4.2. Discussion of the Research Questions

This chapter focuses on answering the key questions previously identified for the study of the dissertation. These are divided into sub-chapters, as analysed below, where each question is discussed according to the information obtained from the selected articles in the SLR.

4.2.1. How has research on material reuse in the construction sector been influenced by the implementation of European Union legislation since the Waste Framework Directive 2008/98/EC?

In one of the initial chapters referring to the presentation of data, the evolution over the years since 2008 was already discussed and, through Figure 4.1, an evident increase in the number of publications over the years was observed. In this way, it is possible to evaluate that since the publication of the European Commission Waste Framework Directive 2008/98/EC, of November 19th, several publications of articles can be observed in the defined time period and it can also be noted that there is a particularly marked evolution in the number of publications per year from the year 2018. This sharp increase from these two years may be due to the publication of Directive (EU) 2018/851, of May 30th, which amended the Waste Framework Directive. It is therefore possible to observe a relationship between the publication of articles with a research focus in this area and the publication of regulations implemented by the EU. One of the reasons for this connection may have to do with the fact that Directive (EU) 2018/851, of May 30th , includes concepts such as selective demolition, which in turn promotes and reinforces the importance of the practice of reuse.

However, it is important to note, as mentioned above, that not all articles focus exclusively on the practice of reuse, so it was explained that a categorised analysis using a 3-points ordinal scale was carried out to assess the level of focus on this practice within the selected articles. Thus, out of the 62 selected articles, only 18 focus exclusively on reuse

(category 3), representing 29.0% of the research focus in this area. While 33 fall into category 2 (not exclusively focused on reuse), the remaining 11 articles partially focus on reuse without application in the results and discussion (category 1). Figure 4.3 shows the evolution over the years of publications falling into categories 3, 2 and 1.

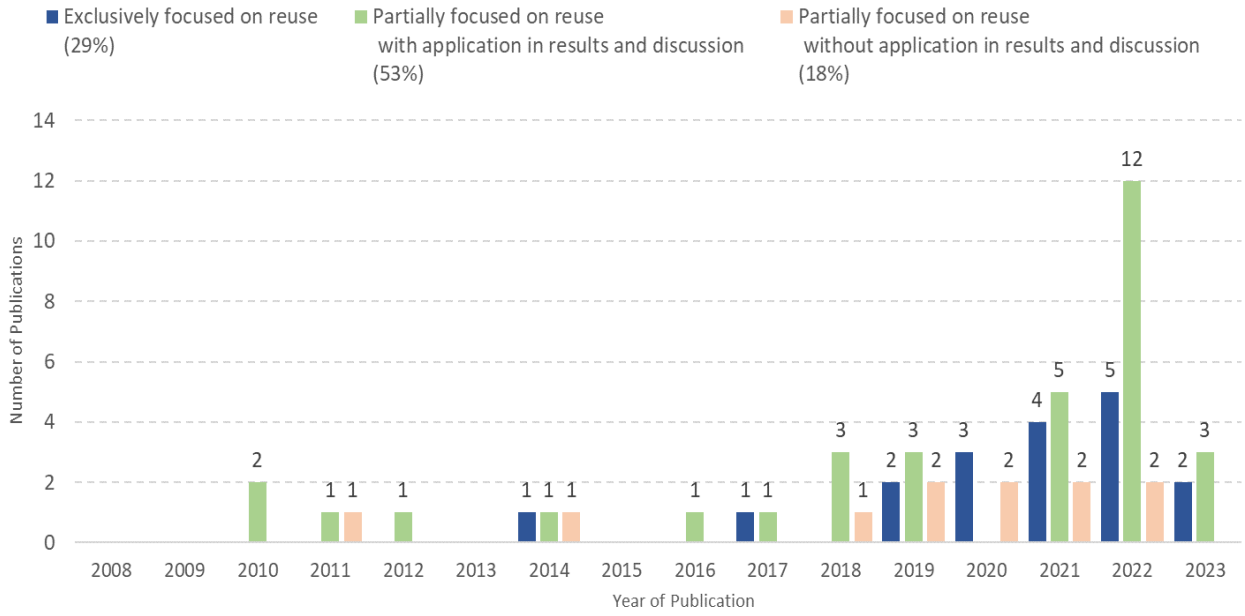

Figure 4.3. Evolution over the years of publications falling into the reuse focus categories according to the context of content

From the figure above, the categories highlight an increase in publications from 2018 onwards. This increase could be due to the publication of Directive 2018/851, in 2018. As it promotes the practice of reusing building materials and the practice of selective demolition, it suggests that this increase in publications is related to these needs mentioned in the Directive.

The figure shows an evolution over the defined period, as already mentioned, and it is possible to conclude, with regard to articles that focus exclusively on reuse (category 3), that during the period from 2008 to 2018, only two publications are observed. However, it can be seen that from this last year, the number of publications dedicated to the study of this practice begins to increase, peaking in 2022 with five articles published in the same year. Regarding the articles partially focused on reuse with application in results and discussion (category 2), and compared to category 3, it can be seen that in the period from 2008 to 2018 there is a greater number of publications that, according to the category, although they do not focus exclusively on the practice of reuse, they also study its practice and mention its

importance. From 2018, as with category 3, the number of publications increases again, peaking in 2022 with a total of twelve publications in that year. For category 1 (articles partially focused on reuse without application in results and discussion), there were few publications without trends until 2019, and from 2019 onwards, although there were also no trends, there was an increase in the number of publications. Thus, although no trend stands out over a long period of time, research therefore pursues the regulatory base, either out of a need to meet legal requirements in the field, or out of an interest in research as an enabler of the practice.

In addition to these results, it can also be concluded that some of the EU countries that present published articles within the selected categories do not present any published articles focusing on reuse (within categories 2 and 3). These countries are the Czech Republic, Luxembourg and Romania. This might indicate a lack of research effort in this area and, consequently, a lack of demand for the promotion of practices related to the reuse of construction materials. Finally, it is noted that several of the countries do not present any articles focusing exclusively on reuse (within category 3). These are Greece, Germany, Ireland and Slovakia. However, although the last mentioned countries do not present articles focusing exclusively on reuse (within category 3), they do present articles that mention the practice and its importance (within category 2), demonstrating their awareness for research in this area through an integrated approach to the concept.

4.2.2. Is there a relationship between European policies and research on the reuse of building materials?

As can be seen from the analysis carried out to answer the previous question, it can be concluded that there has been an evolution in research in the field of the construction sector and its practices, as well as in the practice of reuse, since the publication of the European Commission Waste Framework Directive 2008/98/EC, the publication of the Directive 2018/851 and the Circular Economy Action Plan. It can also be seen that this evolution may have been positively influenced by the publication of the aforementioned directives, which provides an initial answer to the key question at hand.

In order to understand whether these directives, as well as other policies, have influenced research in this area, the articles that mentioned EU regulations, such as and in particular the Waste Framework Directive 2008/98/EC, as well as other policies that may have been implemented, as explained above, were also evaluated. Thus, of the 62 articles analysed, 30 refer to the regulations implemented by the EU, while the remaining 32 do not refer

to these regulations, giving a percentage of 48.4% of articles that actually refer it. In addition, of the 30 articles that refer to regulations, 23 refer specifically to the Waste Framework Directive 2008/98/EC, while only two refer to Directive 2018/851, which amended the previous Directive. Finally, there are still some articles, i.e. seven articles out of 30, which refer to the Circular Economy Action Plan. It is also important to note that some articles refer to more than one regulation, in particular two.

Finally, it is important to identify which of the articles that focus on examining the practice of reuse also mention some of the EU policies in order to make a more in-depth analysis of this issue, since the selected articles have different levels of focus on the research of this practice. In this way, they were divided and defined again into the 3-points ordinal scale already mentioned, which refer to the level of focus on reuse, and these were further separated by the type of policy mentioned. In this way, Figure 4.4 shows the number of publications that refer to each policy, distributed according to the categories mentioned.

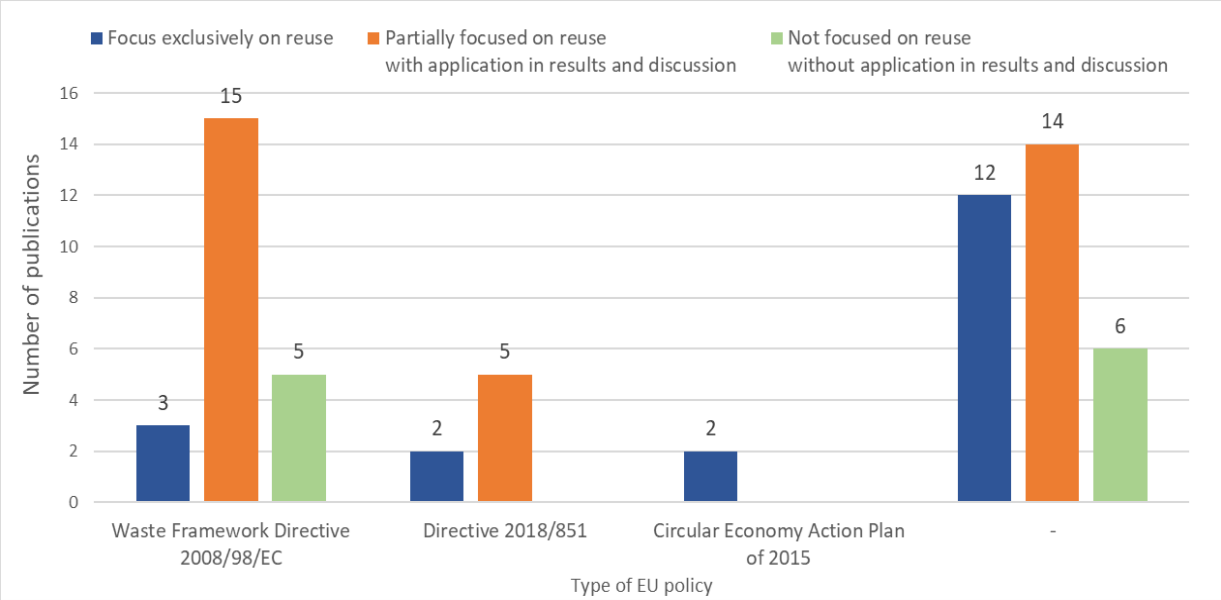

Figure 4.4. Number of publications per category according to the focus on reuse and per type of EU policy

As can be seen in the figure above, with regard to the articles that focus exclusively on the study of reuse (category 3), there is still a significant number of articles that do not mention any of the regulations mentioned above, and therefore no direct link can be made between the study of this practice and the publication of the regulations. However, looking at category 2 (articles partially focused on reuse with application in results and discussion), it can be seen a relevant peak in the number of published articles that mention the Waste Framework Directive 2008/98/EC and also some that mention the Circular Economy Action Plan of 2015, which could mean that this research in this area has increased in line with the

implementation of policies. In the case of articles that do not focus on reuse, there is a balanced number of publications between those that do not mention any regulation and those that mention the Waste Framework Directive 2008/98/EC.

For instance, although it is not possible to establish a direct relation between the number of articles published in category 3 and the mention of regulations in the articles, it is possible to note that almost half of the articles studied mention some type of regulation, compared to the number of articles that do not. It can therefore be concluded that the implementation of this type of policies has led to an increase in the need for research in this area.

4.2.3. What are the themes and trends most addressed by researchers and published in the scientific literature?

Throughout the analysis of the selected articles during the SLR, the most common themes addressed in the research of each published article were also identified, with several themes addressed within the 62 selected articles. Among the themes identified, the most common ones can be highlighted as follows:

- Studies on the strategies that can be implemented in the construction sector in the perspective of a CE;
- Studies evaluating the state of implementation of a CE in the field of waste management in different EU countries or regions;
- Life cycle assessment studies;
- Other less covered topics, such as improvements that can be made to improve the practice of recycling and self-sufficiency studies;

Thus, after analysing the articles, it has been concluded that the most frequently addressed topic is studies on the strategies that can be implemented in the construction sector in the perspective of a CE, as 28 of the 62 articles deal with this topic. Some of the strategies mentioned concern deconstruction, design for disassembly, standardisation and some innovative technologies such as BIM. The second most common theme, with 15 publications in this area, is related to studies evaluating the state of implementation of a CE in the field of waste management. Some of these studies concern countries such as Spain, Portugal, Romania, Ireland and also the Arctic region. Finally, the third most addressed theme, with 13 articles, refers to life cycle assessment studies depending on different construction materials or

different strategies implemented. Other themes, such as self-sufficiency studies and material flow analyses, were less common.

Thus, when evaluating the most addressed topics, it is possible to conclude that during the period defined for the SLR, there has been a focus on research on the state of implementation and strategies related to the CE perspective, as well as on the negative and positive impacts related to this area. In addition, it can be concluded that there is a lack of research in some areas that could also be important to promote CE practices, such as reuse.

This means that these studies in the construction sector should also focus, for example, on the economic component of reuse.

4.2.4. What are the main barriers identified by the authors?

Through the analysis of the selected articles, it was also possible to identify some factors that may be very relevant for understanding the motivation for using reuse as a sustainable practice in the construction sector. Thus, through the articles, it was possible to understand the main barriers identified by the authors for this practice. This knowledge can then be relevant, as it makes it possible to gain knowledge about the factors that may prevent the increase of this practice in the construction sector, as well as to understand what needs to be changed in order for some factors to no longer be barriers.

Thus, the main barriers identified in the 62 articles selected in the SLR procedure are outlined below, which are divided into four different sections: regulatory, social, economic and technical barriers. Table 4.3 further identifies these four sections explained in a more general way.

Table 4.4. Barriers for the practice of reuse per category

General barriers	Specific barriers	Articles
Economic	Logistics costs, such as storage, transport and designated sites for the recovery of reusable materials; Lack of market for reusable materials;	Akbarieh et al. (2020); Vares et al. (2020); Andersson & Buser (2022); Christensen et al. (2022);
Social	Lack of awareness on the benefits of reusing building materials; Lack of experience, knowledge and willingness on the part of stakeholders to change existing practices; Resistance of stakeholders to change the organisation of their daily work; Lack of confidence in the quality of secondary materials for reuse; Lack of cooperation between stakeholders;	Couto & Couto (2010); Ghisellini et al. (2018); Kanters (2018); Nußholz et al. (2019); Anastasiades et al. (2021a); Niu et al. (2021); Marinho et al. (2022); Anastasiades et al. (2023);
Regulatory	Lack of legislative framework for the reuse of components, which can make it difficult for construction stakeholders to navigate safely and responsibly; Lack of standardisation;	Couto & Couto (2010); Kanters (2018); Cai & Waldmann (2019b); Bertino et al. (2021); Niu et al. (2021); Condotta & Zatta (2021); Marinho et al. (2022); Andersen et al. (2022); Anastasiades et al. (2023); van den Berg et al. (2021); Karanafti et al. (2022);
Technical	Lack of infrastructures to store and transport reusable materials; Lack of information on the properties of construction materials;	Couto & Couto (2010); Mihai (2019); Nußholz et al. (2019); Nußholz et al. (2020); Vares et al. (2020); Niu et al. (2021); Condotta & Zatta (2021); Honic et al. (2021); Anastasiades et al. (2023);

Examples of the factors related to each of these areas are expressed in more detail below.

Economic Barriers

Regarding economic barriers, according to Andersson & Buser, (2022), which conducted interviews as part of the study, there is a problem that is often identified by environmental managers working in the construction sector, which is that they are unable to demonstrate the monetary gains that could be made by adopting practices such as reuse. This leads to stagnation in the use of traditional practices.

Another factor mentioned in the selected articles is the fact that there is a lack of a market to promote the sale of reusable construction materials, which is mentioned by Akbarieh et al. (2020). According to Christensen et al. (2022), this type of market is essential and could be physical or digital, the latter favouring the purchase of materials before construction or demolition, which would also reduce logistics and transport costs. The author also points out that many stakeholders find both reuse and recycling expensive.

One of the most frequently cited barriers in this analysis remains the logistics involved in storing and transporting building materials for reuse. This is because these factors require additional costs, as well as the fact that the materials are damaged several times, or need to be tested and quality certified, as mentioned by Vares et al. (2020). According to the author, there is also a lack of designated sites for the recovery of this type of material, which ultimately reduces the number of materials that could be used for reuse.

Social Barriers

Regarding the social factors that are hindering the practice of reuse, one of the most important factors mentioned in the articles is the lack of awareness and willingness (Anastasiades et al., 2021a, 2023; Ghisellini et al., 2018) to learn more about this practice. In addition, the lack of experience and knowledge (Marinho et al., 2022; Niu et al., 2021) makes the work carried out take longer periods of time. These situations mean that this practice is not further explored in relation to its benefits and, consequently, ends up not being used.

It was also noted that this problem can be observed in the opinion of construction workers responsible for several different areas. As an example, according to Anastasiades et al. (2021), manufacturers are reluctant to change the way they organise their day-to-day business or, as another example, contractors do not trust secondary materials for reuse. This last example is also mentioned by Kanters, (2018), which refers a common negative perception by the end user of reused materials. In addition, according to Anastasiades et al. (2023), there is still

a lack of cooperation between the entire team responsible for the construction work, which in turn could help in the transition to a circular use of construction materials through reuse. This lack of cooperation is also mentioned by (Nußholz et al., 2020).

Regulatory Barriers

In terms of barriers related to regulations, a common barrier identified in many of the articles is the lack of specific policies for the reuse of materials by governments (Bertino et al., 2021; Cai & Waldmann, 2019b; Condotta & Zatta, 2021; Kanters, 2018; Marinho et al., 2022; van den Berg et al., 2021). Examples mentioned in the articles include the lack of standardisation (Anastasiades et al., 2023; Andersen et al., 2022; Condotta & Zatta, 2021; Karanafti et al., 2022; Niu et al., 2021). This makes it difficult for the construction sector to start developing and using these practices without specific plans in place, as it does not allow stakeholders to act in a safer way.

Furthermore, according to a study by Condotta & Zatta, (2021), one of the barriers is that there are regulations that are not very clear and do not help to promote reuse. This lack of clarity in the regulations has consequences such as increased construction time, increased costs, and impacts on the perception and performance of the construction activity. Therefore, the authors state that it is essential to resolve this problem. In another study carried out by Couto & Couto, (2010), where they examine the barriers to improving building practices in Portugal, they point to the need for new regulations to improve sustainable practices. This problem is also mentioned by other authors, referring to the lack of sufficient laws and strategies (Cai & Waldmann, 2019b; Kanters, 2018). Other studies also point to the need for a common definition of the concept and perspective of a CE.

Technical Barriers

When analysing the technical barriers mentioned in the articles under study, it is possible to perceive that there are several problems that need to be solved. Among these are the fact that there is a lack of infrastructure on the part of companies in the construction sector that can store materials for reuse (Anastasiades et al., 2023; Nußholz et al., 2019, 2020; Vares et al., 2020), or the lack of transport systems for this same purpose (Mihai, 2019). These factors end up decreasing the availability for the utilisation of this type of materials.

In addition, there is also the fact that building materials vary in size and also in quality, as over time the quality of materials decreases, making it a challenge to find places to reuse these materials. This problem can be observed, for example, when it comes to the

material being wood, since according to Niu et al. (2021), who conducted the interviews for the study, concluded that one of the factors that makes it difficult to reuse wood is the fact that the material is manufactured to be used only once.

Apart from these factors, the lack of information regarding the properties of the materials used in the constructions is also mentioned, which again makes it difficult for stakeholders to reuse these materials (Anastasiades et al., 2023; Condotta & Zatta, 2021; Honic et al., 2021).

4.2.5. What factors do the authors identify as necessary to promote the reuse of materials in the construction sector?

For the study carried out in this dissertation, it was also considered important to know which factors are most mentioned as necessary to promote the increase of reuse of construction materials. Thus, in general, the most mentioned factors are related to economic factors, technical factors, factors related to regulatory changes and standardisation. Table 4.4 further identifies these four sections explained in a more general way.

Table 4.5. Factors necessary to promote reuse per category

General factors	**Specific factors**	**Articles**
Standardisation	Standardisation can improve the adoption of reuse by involving all stakeholders in the creation of standards; Standardisation defines common practices and facilitates the process required to implement reuse;	Hradil et al. (2019); Condotta & Zatta (2021); Anastasiades et al. (2021a); Ottosen et al. (2021); Charlotte et al. (2022); Anastasiades et al. (2023);
Technical	Infrastructure such as transport, storage and sorting facilities are needed; Development of deconstruction techniques such as smarter demolition technologies;	Couto & Couto (2010); Cai & Waldmann (2019b); Etienne et al. (2022); Almeida et al. (2022); Schützenhofer et al. (2022); Anastasiades et al. (2023); Gordon et al. (2023); Klinge et al. (2019);

General factors	Specific factors	Articles
Economic	There is a need to carry out studies to understand the financial benefits of investing in the reuse of building materials rather than traditional practices; Introducing appropriate taxes on landfill; Developing markets for reusable materials can be a good economic incentive;	Schützenhofer et al. (2022); Freire-González et al. (2022); Nußholz et al. (2020); Banias et al. (2022);
Policy	Pre-demolition audits and other types of strategies to promote reuse should be established as mandatory by national governments;	Ghisellini et al. (2018); Spišáková et al. (2022); Condotta & Zatta (2021); Nußholz et al. (2019); Christensen et al. (2022); Couto & Couto (2010);

Examples of the factors related to each of these areas are expressed in more detail below.

Standardisation

One of the most frequently mentioned factors in the articles is the need for standardisation to promote reuse. The fact that there are no harmonised standards for construction materials, while technical specifications do not mention the necessary conditions for reusable materials, such as how to test the components (Charlotte et al., 2022; Condotta & Zatta, 2021; Hradil et al., 2019), makes this practice less widespread in this sector (Anastasiades et al., 2023).

As an example, according to Ottosen et al. (2021) which conducted interviews in his study, several stakeholders believe that it is possible to improve the use of reusable materials in the construction sector, but that there are still several problems, such as the fact that materials are not certified and that standardisation is the way to start improving the adoption of this practice. In addition, there is also articles that mention that all stakeholders should be involved in the process of creating standards for reuse, as it is necessary for all stakeholders to agree and raise awareness in this area (Anastasiades et al., 2021b, 2023). Hradil et al. (2019) also suggests that standardisation should be introduced at the beginning of the project, for example in the design phase.

Thus, it can be seen that the definition of standards is very important to increase the practice of reuse because it defines common practices and, consequently, facilitates the processes necessary to carry out this process.

Technical Factors

Another area that is often mentioned throughout the articles concerns technical factors that can be improved in order to promote reuse. One of the most mentioned factors concerns the infrastructure necessary for this practice, such as the transport of materials and their storage, as well as sorting facilities (Anastasiades et al., 2023). According to Almeida et al. (2022), as an example, in this context, it is necessary to set up storage sites for the materials in order to be reused. In addition, logistics need to be set up to link demolition sites with sites where new buildings are being created to allow for a flow of materials between projects (Schützenhofer et al., 2022). In addition, according to Cai & Waldmann, (2019b), the development of dismantling procedures in deconstruction should be promoted and more smart demolition technologies should be developed (Gordon et al., 2023; Klinge et al., 2019).

Another aspect mentioned by Etienne et al. (2022), is the fact that it is often assumed that the reusable materials will be used in different works at other sites. However, this does not have to be the case, as the separation of these materials can be done *in situ* and the materials can also be used on the same site, in order to avoid transporting the components to other sites.

Economic Factors

Regarding the economic factors mentioned by the authors as promoting the practice of reuse, there are several options that are suggested. The economic factors should be studied as they are essential aspects to promote their actions in companies (Schützenhofer et al., 2022).

One of the factors mentioned by Freire-González et al. (2022), is due to the implementation of landfill and incineration taxes, which can encourage stakeholders to look for other types of alternatives. In addition, as mentioned above, the creation of markets for these types of construction materials can be a good economic incentive and create competitiveness (Banias et al., 2022). Finally, it is also mentioned by different authors the need to carry out studies to understand the financial benefits of investing in sustainable practices compared to the continued use of traditional practices (Nußholz et al., 2020; Schützenhofer et al., 2022).

Policy Changes

Regarding factors related to regulations, there is also a diverse range of needs mentioned by the authors, and some strategies have already been created and suggested. This is the case for pre-demolition audits, which although protocols already exist, it is not yet mandatory in all countries (Condotta & Zatta, 2021; Nußholz et al., 2019), and this fact, is also mentioned by Spišáková et al. (2022), who argue that it should be an integral part of projects in the construction sector. The authors argue that although it is not mandatory to comply with the rules of the pre-demolition audit, this waste audit would be very beneficial for stakeholders who implement it, as it would help stakeholders to increase their sustainability levels in terms of using more sustainable materials. Again, according to Spišáková et al. (2022), there are significant differences in waste management assessments carried out in countries that follow these documents compared to countries that do not yet implement these ideas. In this way, governments of different countries and companies in the construction sector could implement the obligation of certain policies, which in turn would help to increase systemic practices in the sector.

In addition to the categories of factors already mentioned, there are other factors that can be evidenced in the analysis of published articles, such as the need for more awareness on the part of stakeholders. According to the study conducted by Christensen et al. (2022), the creation of a platform in order to be able to share different expertise in the area, allowed to increase the motivation to act and links between different organisations.

4.2.6. How Researchers Use the Concept of Reuse?

Through the analysis of the selected articles, it became clear that concepts related to a CE perspective may not be fully understood and consequently not properly applied by stakeholders. This problem arises in different concepts, but also when one concept is confused with another when talking about a practice and as already mentioned, it is important to promote equal standards for all stakeholders. The same should be done with concepts.

Some articles, such as a study by Ottosen et al. (2021), have also analysed that there is a lack of a common concept of CE and that this problem is still perceived by stakeholders. The problem of common concepts between stakeholders was further noticed by a study with interviews conducted by Schützenhofer et al. (2022), who mentioned that they confused the concepts of deconstruction and demolition, and also mentioned that this was also happening

with the concepts of recycling and reuse. In this way, during the analysis of the selected articles, it was noticed that sometimes the concept of reuse was not used in a fully correct way.

From this analysis it can be concluded that most of the 62 articles apply the concept of reuse well. According to the 3-points ordinal scale explained in the methodology chapter, 96.8% of the articles refer to the articles that fully apply the concept of reuse as defined in the Waste Framework Directive (category 3). Thus, only 2 articles (3.2%) fall into the articles that sometimes misuse the concept (category 2), and no articles fully misuse the concept of reuse (category 1). Within the articles in category 2, examples of misuse of the concept are the use of the word reuse when referring to the use of materials for reuse after pre-processing such as grinding the material, the use of the word reuse to refer to materials that will be used for other purposes. This shows that there is some confusion in the use of the concepts according to their definition, but nevertheless they did not completely misuse the concept throughout the study, which could mean that this event could just be a lapse in the correct use of the concepts.

4.3. Critical Analysis

The results obtained through this SLR intended to better understand the research carried out by authors from different EU countries on the management of CDW and the practice of reuse in the construction sector. Through the methodology adopted and the articles selected and analysed, there can be benefits for understanding more appropriate policies to be applied/adapted to this sector, and for promoting the practice of reuse of construction materials.

Therefore, when evaluating and discussing the results, it was concluded that there is a need for more research in the different areas directly related to the topic. Although there has been an evolution in the number of publications over the years in the area of CDW management, the implementation of a CE perspective and the practice of reuse, many of the selected articles did not fully focus on reuse. Thus, despite the fact that some of the articles present an integrated view of the practice of reuse, there should be a greater number of publications focusing only on reuse, in order to better learn how to promote this practice in the most appropriate way, given the importance it can have in promoting circularity in the construction sector, being one of the most prioritised practices in the WH. Some research that should be further strengthened concerns financial and social studies that help promote the benefits of this practice.

In addition, it was possible to conclude from the analysis of the results that the EU countries are at different levels of evolution in terms of waste management. Although it is noticeable that many of them are guided by the regulations that are published by the EU, there are countries that clearly show more progress than others, and those that have achieved more progress have managed to evolve more in their levels of recycling and reuse rates, as is the case of Finland. These developments in countries should be promoted, especially in those that do not yet show much progress, as these are important for pollution prevention, economic aspects and job creation.

The different levels of progress observed in the different countries can be linked to another aspect analysed in this study, which relates to the barriers that hinder the promotion of reuse, which are mainly observed in economic, social, regulatory and technical aspects. These aspects, which have already been discussed in more detail in the discussion of the results, should be studied in more depth in order to be able to remove these barriers in the most appropriate way. These barriers, despite their impact on the promotion of this practice, should not obscure the fact that this practice can bring many benefits to the construction sector, such as reducing the pressure on companies to improve their environmental footprint, or even improving the economics of companies. In this way, further research can help make companies aware of the benefits they are not yet taking advantage of. One of the barriers mentioned in the articles is cost, as mentioned above. However, and as an example, it should exist more motivation to encourage research into how to make this practice cost-effective, as this is a very promising factor for improving stakeholder opinions. Lastly, it is important to mention that the identified barriers are important to understand where the next studies can focus to start removing factors that hinder reuse.

Another important factor to mention, which was concluded during the results, is the fact that the concept of reuse can be used by the authors with different objectives, since it can also be used in a general way the practice of repurposing materials. However, it has been observed, even if only in a few articles, that this concept has been used less correctly when talking about the reuse of building materials. Therefore, it is important that there is a common understanding of this concept as a practice from a CE perspective and using it in different ways can lead to an incorrect understanding of the research in question, as well as impact on the evaluation of a series of studies on this practice, or even on the subsequent definition of strategies to be implemented to promote it.

Finally, it is important to mention that several of the publications mention in a general way what are the barriers and factors that can promote the practice of reuse in the construction sector. However, the way in which countries operate in these sectors is different, so these factors still need to be carefully studied for each country that seeks to improve, in order to identify what is most appropriate depending on the country and situation being studied.

5. Strategies and Good Practices to Promote Reuse

The current needs of the construction sector, with the increased development of the sector and the need for new infrastructures, means that it must look for innovative ways to reduce its environmental footprint. The development of sustainable practices, such as reuse, is therefore of great importance, since by extending the life of construction materials, there is consequently less demand for the extraction and production of new materials, as well as a decrease in the amount of CDW generated. After presenting and discussing the results obtained, it was possible to draw several conclusions and to gain a better understanding of the problems that hinder the promotion of reuse, as well as the existing needs for this practice to become more widespread. Therefore, this chapter focuses on proposing strategies and good practices to promote reuse in the construction sector in the EU countries. These suggestions are presented and discussed below.

One of the main problems analysed in the study carried out in this dissertation concerns the lack of awareness and cooperation among the different stakeholders in the sector, as well as a certain resistance to the changes needed to implement reuse. Therefore, one of the main strategies that should be implemented is the introduction of knowledge sharing for this practice. This can be done, for example, through workshops for companies that present the processes that need to be implemented as well as the benefits that can be gained by implementing this practice in construction activities. This can include professionals with knowledge of the practice who can also provide lectures and training programmes on the techniques used in the procedure. These, in turn, can provide new skills for people working in different areas of the company, such as architects, engineers and contractors. It would also be a good option to include workshops that bring together stakeholders from different companies to encourage collaboration between them, namely those working manly with the subcontracting regime.

Another factor frequently mentioned in the problems hindering the practice of reuse, as well as the need to promote this practice, concerns factors related to regulation and the need

to define common practices to facilitate the process of reuse. In this way, common guidelines should be developed that can be used by all companies in the sector, presenting common reuse standards, facilitating the various processes needed to comply with this practice and, in turn, facilitating the work of the different workers. This standardisation will therefore help to avoid doubts about different situations within the reuse processes and promote confidence in the use of this practice as well as in the use of reused materials.

Another factor that should be used to promote reuse is financial incentives, as this area is very important in terms of encouraging the various companies in the sector. In this way, research should be supported with financial studies that highlight the differences between using reuse as a practice or not. By showing companies that this practice can bring financial benefits, it will encourage them to start using this sustainable practice. In addition, this type of study can also help companies understand which reuse processes are best suited to make the practice more cost-effective.

One of the most important factors to consider is the preparation for reuse in the different phases of construction projects. In order to improve and maximise the processes and benefits of this practice, it is necessary to pay attention to the characteristics of the project at the different stages in order to prepare for the reuse process. This awareness should be taken into account right from the initial project phase and it is suggested that for all construction projects extra care should be taken in the design phase of the new project, i.e. it is essential to implement preparation for reuse in the project planning phase. In this way, a project can be prepared taking into account the use of materials that can be reused in new projects at the end of the life of the building, for example by using materials that are easier to separate from the rest of the materials in the building. Once again, the principle of standardisation can be applied from this perspective, as the use of standardised components also facilitates the process of reuse in other construction projects.

Another example of a process that should be implemented in all projects is selective demolition. This process, together with the initial project preparation mentioned above, helps to maximise the materials that can be recovered at the end of a building's life, as more materials are recovered that can be reused later. Therefore, when this process is added to all projects, an inventory of all recovered materials should also be added to make it easier to organise and understand all the ways in which materials can be used later.

These factors go hand in hand with another strategy that has already been suggested, and which should be made mandatory in all end-of-life building demolition projects:

pre-demolition audits. These should be mandatory in order to facilitate various circular economy strategies, such as reuse. These audits should be conducted in such a way as to identify all materials and the quantities of those materials that can be recovered instead of becoming waste. In this way, audits also allow future plans to be made for the use of reusable materials through an inventory.

In turn, this type of practice is linked to other strategies that are essential to maximise the reuse of materials. These include the need for the entire construction sector to introduce material passports. This strategy can be of great benefit to the various construction companies, as the use of this type of documentation facilitates the process of pre-demolition audits, as there is already characteristic information on the properties of each construction material found in the building. This makes it easier for the specialised teams working on the project to determine which materials have the potential for reuse and are suitable for future use on other projects. In addition, material passports have the added benefit of giving subsequent users of reusable materials greater confidence in the materials being used.

Another aspect considered essential to promote and maximise the reuse of construction materials is the implementation of a national digital marketplace for this type of secondary material, which is one of the strategies recommended for implementation. Although some online platforms already exist for this type of market, these should be developed, promoted and advertised so that all stakeholders in the construction sector are aware of and seek to use it. These marketplaces provide a bridge between the materials recovered at the end of construction projects and the start of new projects, allowing secondary materials to be used instead of the typical search for new materials that results in increased extraction of raw materials. As well as benefiting one company, it also encourages collaboration between companies, as any company can use materials that another company has placed on the platform.

In addition, secondary materials markets have the advantage of providing lower cost materials than virgin materials for future projects in various countries, although this also depends on other factors, such as the amount of virgin materials available in each country. This also provides a financial incentive for the company that owns the materials by making them available for sale. It is also important to note that these factors are linked to financial factors in other ways. In other words, although the implementation of selective demolition and auditing processes can be costly, for reasons such as the need to hire specialised labour and the fact that they also increase project duration, the introduction of this type of market helps to

recover this type of financial expense. Once again, it's important to mention the need for research in this area in order to provide companies with an analysis of the financial benefits that can be obtained by combining these types of methods.

Finally, it has also been analysed that there are several problems related to technical barriers to promote reuse, such as the need for new infrastructures prepared for the processes of this practice or infrastructures with adequate distances to reduce transport costs, as well as the impact of fuel vehicles on the environment, for example. It was therefore concluded that the implementation of material banks is essential. These allow construction companies to create places where secondary materials can be stored. These should be implemented strategically in order to reduce one of the problems highlighted in the results, which is the cost of transporting this type of material. In addition to the fact that material banks can be implemented by each company, they can also be implemented through cooperation between several companies and then shared by them. In addition, it is suggested that the government also evaluate this implementation, as it can implement this type of storage for public works and also cooperate with private companies so that they can also use it. For example, the government should consider setting up material banks in municipalities to facilitate the transport and storage of materials within the construction areas, or in different regions of the country, which, if necessary, also included transfer stations. Once again, the implementation of this strategy is linked to the other factors suggested, maximising the opportunities for reuse, whilst construction companies can benefit greatly from linking this type of storage with the information available in material passports and digital market platforms.

6. CONCLUSIONS

6.1. Conclusive Summary

The main objective of this dissertation was to understand the development of research on reuse in EU countries after the implementation of several regulations, such as the Waste Framework Directive 2008/98/EC (amended by Directive 2018/851), and to understand the barriers that hinder this practice and the factors needed to promote it. Therefore, another objective was to define strategies to promote the practice of reuse in the construction sector.

In order to achieve the desired objectives, a literature review was first carried out in order to present the challenge of managing CDW generated by the construction sector, the different issues in a circular economy perspective related to reuse, as well as the importance of implementing this practice in the construction sector. A systematic literature review was also conducted as a method, which, through a process of searching and selecting articles limited to countries belonging to the EU, led to the analysis of 62 articles published since 2008. This provided a unique assessment focused on analysing the impact of the European Union strategies and legal frameworks implemented to promote reuse, and how these policies have influenced the direction of research in this field.

After analysing the articles, it was possible to draw several conclusions about the development of research on this practice in EU countries, concluding that the countries have widely different levels of development and research on this practice. It was also possible to identify correlations between the publication of policies such as the Waste Framework Directive (Directive 2008/98/EC, of November 19th), amended by Directive (UE) 2018/851, of May 30th, and the increase in research on the practice of reuse by EU countries.

In addition, the analysis of the articles made it possible to draw conclusions about the barriers and factors needed to promote reuse, and to critically analyse these results. Thus, it was possible to conclude that the main barriers that prevent this practice are mainly

observed in economic, social, regulatory and technical aspects, such as the lack of cooperation between stakeholders, lack of confidence in the quality of secondary materials and lack of infrastructures to store and transport reusable materials. It was also possible to conclude that the main factors that stand out as necessary to promote this practice in construction companies are economic, technical, regulatory and standardisation related, such as the need to develop markets for reusable materials, the need to strengthen studies to understand the financial benefits of investing in the practice of reuse, and the need to develop smarter technologies, for example in the deconstruction process. In addition, it was concluded from this study that there is still a lack of research and a lack of focus on the promotion of this practice through strategies that are implemented at an early stage of the project.

By analysing these results and making connections among the findings, it was possible to achieve at the final objective of the dissertation, which was to consider strategies that should be implemented to promote reuse in the construction sector. It was suggested that information-sharing mechanisms should be implemented, such as workshops to share the benefits of reuse for the different stakeholders, the implementation of common regulations to standardise the processes required for this practice, the use of processes such as design-for-reuse, mandatory pre-demolition audits, the sector-wide implementation of material passports, the creation of a national digital market for secondary materials and the establishment of material banks in different strategic locations to facilitate the transport and storage of construction materials.

Finally, the results can also be used by stakeholders to understand what is influencing the adoption of this practice and what construction companies should look to improve in order to start promoting more sustainable practices and in turn reduce their environmental footprint. In addition, the results can also be used by future researchers, companies and decision-makers to gain a broader understanding of what areas still need to be explored in order to improve certain aspects that may not yet be well understood.

6.2. Limitations and Future Research Recommendations

This study focuses on the practice of reuse in the construction sector in EU countries, as well as the barriers and factors that promote this practice, in order to subsequently understand which strategies should be implemented to promote it.

One of the purposes of this study was to assess the impact of EU policies on research in this area, and it should be noted that not all policies implemented by the EU were used, which

might be interesting to assess for this purpose. Furthermore, the fact that this study focused on EU countries may have limited some of the information gathered, such as the barriers and factors that promote reuse, as there are other countries outside the EU that may have innovative perspectives to promote reuse in the construction sector. Finally, as this study focuses on a SLR, there are stakeholder perspectives in this sector that may not have been analysed specifically for certain stakeholder groups or groups of companies with specific challenges.

It is therefore recommended that in future studies, in addition to the policies selected for this study, other types of regulations published by the EU or specific to each EU country should be used for comparative analysis. As each country operates in a different way, it is recommended that studies should be carried out that focus on each country and its regulations, in order to identify what is most appropriate depending on the situation being studied.

Furthermore, after discussing the results, it is also proposed that more studies should be carried out that focus exclusively on the practice of reuse, such as financial studies that examine the different project phases and compare the results with traditional practices already in use.

Finally, considering that this study has focused on a methodology based on a SLR covering different articles from EU countries, studies should also focus on other countries outside the EU and it is also recommended to carry out studies for each country, including interviews with construction companies and other stakeholders in the sector value chain of construction materials. This methodology can complement studies such as this one, covering a different and important perspective to be evaluated in order to study reuse in this sector.

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NOVA SCHOOL OF SCIENCE & TECHNOLOGY