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Waste-based materials in residential house construction

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Abstract

Waste from the construction sector has been increasing considerably in recent years, making it urgent to find alternatives to this waste that will enable us to preserve the environment and ecosystems. Many studies demonstrate the viability of using this and other waste in the construction sector, such as wood, ashes, and plastics. This article presents a review of research works where residual materials have been applied in the construction sector. To achieve this objective, a total of 35 articles were reviewed, published in English-speaking journals between 2015 and 2023. This review shows that, although in recent years efforts have been made for the application of waste materials in the construction sector has been significant, however, there is still work to be done in the study of the behavior of these residual materials, such as the emission of greenhouse gases, as well as the importance of residual materials pretreatment to ensure compatibility with the rest of the components. Another important aspect is that most studies consider environmental aspects without taking into account social and economic issues surrounding them in the construction sector.

Keywords: Waste; construction materials; energy efficiency; environmental impact

1. Introduction

Construction and demolition waste (C&D) is the largest waste stream in the EU, according to European data (European Commission, 2018), with C&D waste accounting for around a third of all waste generated in the EU.

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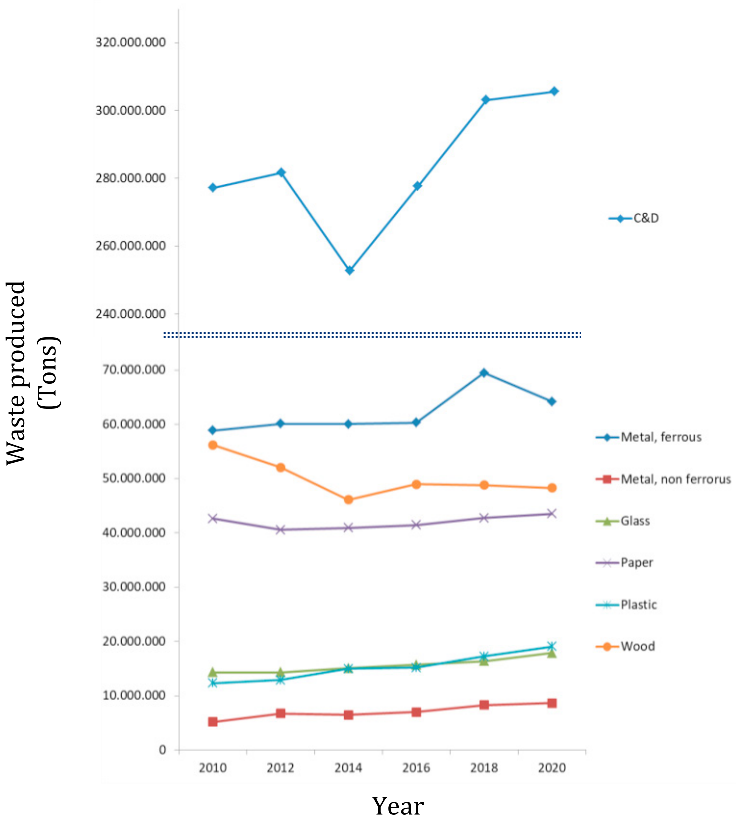
Throughout the life of one European citizen, around 160 tons of C&D waste can be generated. The Waste Framework Directive (EU) 2018/851 had the aim of recycling 70% of C&D waste by 2020. However, most member states only recycle around 50% of C&D waste. Figure 1 shows the waste tons produced in the EU from 2010 to 2020 and the increase in waste generation in recent years, with construction and demolition waste being by far the largest generator.

The lack of confidence in the quality of the waste materials and the lack of knowledge about the potential health risks are the main barriers to improving the rates of recycling and reuse of C&D waste. This lack of trust decreases demand for C&D wastes recycled, which slows down the development of C&D waste management and recycling infrastructure in the EU (European Commission, 2012). For that reason, in 2016, the European Commission presented the EU Construction and Demolition Waste Protocol (European Commission, 2016).



ɔstat, 2023).

Fig. 1. Evolution of waste production in the European Union from 2010 to 2020 (Eurostat, 2023).

The Construction and Demolition Waste Protocol is part of the EU Construction Waste Management Strategy 2020 (COM (2012) 433) (European Commission, 2012) in addition to the Communication on Resource Efficiency Opportunities in the Construction Sector (COM (2014) 445) (European Commission, 2014). This protocol is also part of the Circular Economy Package adopted by the European Commission in March 2020 (COM (2020) 98 final) (European Commission, 2020). The main goal of the Circular Economy Package is to encourage sustainable products in those sectors that need raw materials and have a high potential for waste recirculation, as in the case of the construction sector. The aim of the package is to decrease the use of energy and non-renewable resources, reuse construction components or products as much as possible, reinforce the restoration of old buildings and reuse components whenever possible (Wang, 2018). Those are the main reasons behind Green Building. Green Building refers to buildings whose structure and orientation use less energy or even reuse water. Green Building also entails the use of environmentally friendly materials and resource-efficient processes throughout the entire life cycle of a building:

from the design of the building, through the extraction and transportation of raw materials, the construction stage, the use and maintenance stage of the building, the renovation, and the final demolition to recycling waste.

Taking into account the initiatives proposed by the European Commission and considering the initiatives for a circular economy in the construction sector, some research efforts have focused on studying how the addition of different kinds of waste, such as construction waste, industrial waste, and agricultural waste, affects construction materials and the structural properties of buildings. This alternative can add value to waste by returning it to the production chain without causing human or environmental damage. Recent studies have shown that the addition of waste to construction materials can improve mechanical and thermal properties and reduce environmental impacts (Guo, 2018), as is the case with the addition of ashes resulting from a biomass combustion process in the manufacture of conventional bricks (Sutcu, 2019; Muñoz 2021), the addition of paper pulp waste (Muñoz, 2020) and the use of iron ore tailings in the construction of clay bricks (Mendes, 2019). These studies have demonstrated the technical and environmental feasibility of incorporating different waste into main components for the production of material construction. In addition, the material obtained is inert and non-hazardous. Another study used wheat straw waste, sunflower seed cake, and olive stone flour to produce bricks (Bories et al., 2015). During the last decade, some research demonstrated that incorporating waste in the construction materials increases porosity, water absorption and thermal insulation and is correlated with a decrease in bulk density and flexural strength. Moreover, these studies demonstrated the technological and environmental advantages of reusing this type of waste. The research also point out that this alternative leads to reduced costs due to the use of waste to replace clay and reduced transport costs due to the production of lighter products.

For the reason briefly introduced in this section, the main purpose of this research is to analyze the current state of the use of residual materials in the construction sector. Particularly, we aim to answer the following questions.

- What is the current trend in the use of waste materials in the construction sector?
- What are the recent issues that we must face in construction waste material?

In order to answer these questions, the information has been collected from the scientific literature and a description of the main residual materials used has been analysed. In addition, a description has been carried out of the current trends in waste materials in construction and the recent problems that we must face to promote the use of these waste materials and promote the circular economy in this sector. After this brief Introduction (1), we present our concept and methodological description of the analysis of the reference bibliography (2). The results of the bibliographic review are presented in Chapter 3, where the questions raised at the beginning are answered. Chapter 4 offers the final conclusions.

2. Materials and methods

The methodology used to carry out this study has focused on 4 steps (Fig 2), following the methodology proposed by Rowley et al (2004): (1) Formulate the questions that are the objective of the article. (2) Select the relevant articles in the study. (3) Analyze the information provided by the selected articles. (4) Evaluate the scientific articles analyzed and answer the questions initially posed.

Step 1: Questions formulation. This review article focuses on answering the questions previously asked.

Step 2: Find relevant references in this field of research. To analyse the most relevant paper, the ScienceDirect and Web of Science databases were used as an electronic database through a search structured by keywords. The keywords of the research were: sustainable construction, construction and demolition waste, sustainable raw materials, green buildings. A period of time from 2015 to 2023 has been considered. A total of 280 papers were found under these premises.

Step 3: Analyse the information provided by selected articles. Of all the selected articles, those articles that do not use residual materials or that do not consider sustainable construction materials were discarded. A total of 35 articles were reviewed to achieve the purpose of the paper.

Step 4: Evaluation and response the questions proposed. This step includes the analysis and synthesis of each study included in this review article. The results are discussed in the following section 4 of this article and answer the research question previously formulated in step 1.

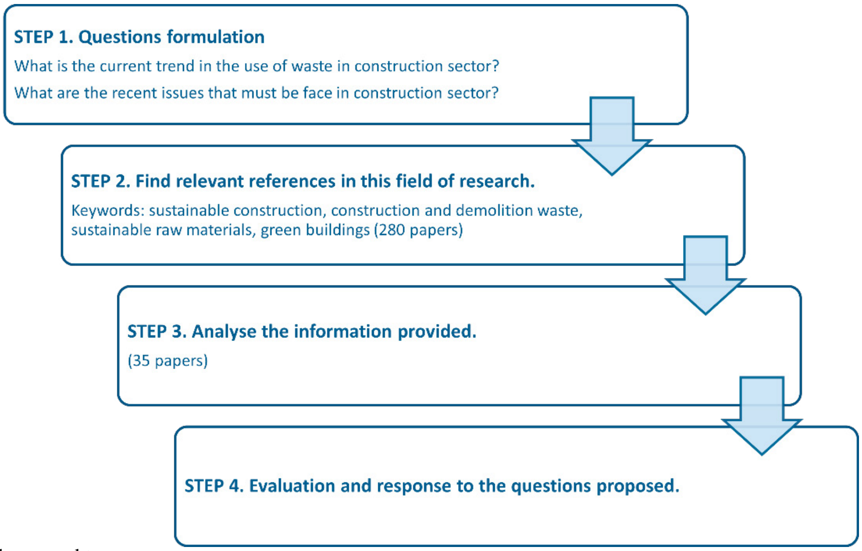


Fig. 2. Methodology used to accomplish the results.

3. Results

This section shows the main results obtained from the review carried out. This section has been divided into 3 sections as shown as follows:

3.1. Current status of construction waste classification

Rubble, concrete, steel, and wood are some examples of wastes generated in the construction sector. It is important to consider that waste is the worst problem in the construction sector and has significant implications for energy efficiency and a negative environmental impact. Construction and demolition waste are generated during the stages of building construction, maintenance, and final demolition. This waste is assorted and includes brick, concrete, cement, glass, wood, and plastics. Some construction wastes are dangerous because they generate leaching, which can impact the environment or even generate toxic substances during the degradation process and which might be dangerous to human beings. Therefore, it is crucial to properly manage this waste (heavy metals, paints, solvents, and asbestos) (Barbuta, 2015). The primary wastes from construction and demolition are listed below:

- Mineral waste: During the extraction process of raw materials and the production stage of construction materials, significant amounts of mineral waste are generated. Such waste includes granite, marble, and limestone. Using these residues could mitigate the negative impacts on the environment and offer significant energy savings (Barbuta, 2015).

- Inert waste: Harmless inorganic waste is a common waste of the construction sector. Harmless waste is not chemically or biologically reactive and does not break down over time. Among the inert waste, we can find sand, plaster, concrete, and cement, among other types (Barbuta, 2015). Reuse of this waste allows significant economic savings, energy savings and reduced environmental impacts.

- Wood waste: Wood is one of the construction materials that has the greatest potential for recycling since it is used in many construction elements as well as doors, windows, boards and so on (Cetiner, 2018; Berger, 2020).

- Plastic waste: Currently, plastic material is an essential waste category where most of it can be reused. Different types of plastics are used to produce concrete, such as polypropylene, polyethylene, polyvinyl alcohol, polyvinyl chloride, nylon, aramid and polyesters. One of the most frequently used plastics is polyethylene terephthalate (PET), since it is used for food packaging. The disposal of these types of waste creates serious problems for the environment (Ahmed, 2023). Some PET waste is recycled as short fibre reinforcement in structural concrete, synthetic coarse aggregate for lightweight concrete, or resin for polymer concrete (Kim, 2010). Plastic manufacturers also produce plastic waste as rejected raw material, which can be recycled to produce building materials (Zelinskaya, 2019).

- Steel: This material can be reused and transformed into other products or used as scrap. To reduce pollution from its production, researchers have replaced part of the cement and natural aggregate content with industrial by-products such as steel slag, ferronickel slag, copper tailings, and copper slag (Kurniati, 2023).

- Glass: Glass recovered as waste can be melted down as fibreglass for reuse. Recycled glass is a good option as a component based on construction materials. Numerous research works show the potential of recycled glass to be used as a substitute for aggregates and/or cement (Mohajerani, 2015; Lu, 2019; Sandanaya, 2020).

- Hazardous waste: The sources of hazardous waste include fuels, paints, silicone and sealing products, battery oils and lubricants, antifreeze, adhesives, strippers and solvents, and wood treated with toxic products. These residues require a specific management process to avoid environmental contamination and health risks.

3.2. Current trends in construction waste materials

In recent years, waste from different sectors has been used to reduce costs. Such waste can be classified as follows (Barbuta, 2015):

- By-product waste is that waste that is generated as a consequence of industrial processes. This classification includes grinding slag, fly ash, silica fume, metals, glass and recycled aggregates. These wastes are mixed with cement to reduce the extraction of minerals from the soil and, in turn, reduce atmospheric pollution (Wang, 2018). Fly ash is waste from power plants or from various solid material incineration processes. Fly ash from municipal solid waste incineration (MSWI) can be used as raw material in sintering and cement preparation (Guo, 2014). Other studies demonstrate that the use of ashes from biomass combustion in the manufacture of bricks shows similar mechanical behaviour to conventional brick. In addition, the use of these residues in construction materials yields a savings of 5% in the carbon footprint and 4% of energy consumption (Muñoz, 2021).

- Natural fibres: Natural fibres are forestry products that are usually classified as waste. They are environmentally friendly, low-cost materials. Among them, we can find curauá fibre (*Ananas erectifolius*) (Bilcati, 2018), piasava fibre (*Attalea funifera*) (Nunes, 2016) and hibiscus fibre (Moses, 2015), which have good properties as reinforcement in various cement mortars. The presence of these natural fibres in cement has been shown to improve tensile and flexural strength, reducing the development of microcracks and improving the internal effects of the cement (Wang, 2018).

- Waste water sewage sludge: The progressive increase of this type of waste poses a difficult waste management problem. One of the solutions to the ongoing increase of this waste is its employment in the construction sector. Using sewage sludge in construction materials eliminates some of the costly and energy-intensive utilization steps. In addition, the final product obtained is typically stable and safe (Swierczek, 2018). The sludge and ashes from the burning of the sludge can be used to produce ceramic products such as tiles, bricks, and pavement. Investigations have been undertaken in this field (Orlov, 2020; Wolff, 2015).

- Paper industry sludge: The paper industry has paper sludge as a by-product, which has a high calcium carbonate content, organic matter and other minerals. Due to its pozzolanic activity, paper sludge can be used with cement mortars, concrete, and ceramics in the construction industry (Cusido, 2015; Vashistha, 2019; Mymrin, 2020).

- Agricultural waste: Agricultural wastes such as cork, straw, cellulose, coconut fibre or cotton are often used as building insulating material. Using these materials in the construction sector decreases the environmental impact (Massoudinejad, 2019). In addition, they contain large amounts of CO_2 captured from the air, so their use in buildings contributes to reducing CO_2 emissions in the atmosphere (Bozsaky, 2019). Certain agricultural residues, such as rice husks, banana leaf ashes, bamboo leaves or bagasse ashes, present pozzolanic activity, which is why they are used in the manufacture of high-resistance concrete (Barbuta, 2015; Tiza, 2021; Dhiman, 2022).

3.3. Recent issues in construction waste material

Currently, the main waste materials recycled in the construction sector are ash and cement waste since they have demonstrated good structural properties and pozzolanic activity and are compatible with traditional materials (He, 2021). These materials have shown good structural properties that enable reduction in the use of raw materials, a reduction in residual materials, and a reduction in CO_2 emissions in the cement production process, thus mitigating environmental impacts throughout the life cycle of the building. However, some authors have shown that cement adsorbs CO_2 during its life cycle so that during the use stage of the building, the use of cement reduces the amount of CO2 in the atmosphere. For this reason, it is necessary to study CO_2 absorption during the use stage of the building and see if a balance is achieved between the CO_2 emission during the production process and the CO_2 absorption during the use stage of the building. Moreover, some researchers have shown that the incorporation of ashes increases CO_2 emissions due to the decomposition of carbonates and water consumption, which highly affects the ecosystems (Muñoz, 2023).

As explained above, plastic waste has been studied for its use in construction materials for a long time; for some years, this waste material has been a top priority due to the large amount of plastic waste that is generated, and it is increasing, as can be seen in Figure 1. For this reason, managing this waste is essential to safeguarding and restoring the environment. Recent studies have analysed the viability of using plastic waste in cement (Sandanaya, 2020; Tawab, 2020; Qi, 2023), and among polyethylene terephthalate (PET) is used the most because it is widespread used to produce water bottles and food. On the other hand, as recently indicated by Kazemi et al. (2021), most studies conducted on construction materials have not taken into account the importance of pre-treating waste polymeric materials to ensure their compatibility with construction materials. Consequently, there is a critical need to understand the science of polymer functionalization in order to adjust the surface properties of recycled granules for specific applications.

Wood scraps are another type of waste that is widely used today in the construction sector. Wood waste can be found in different shapes, including offcuts, shavings, sawdust, slabs and bars. However, these wastes also contain other types of materials such as nails, hinges, and anchors for structures. Wood chips, including fragments, can vary in size and may cause health risks. In addition, wood waste can be irregular in shape and is not always suitable for reuse. For these reasons, the collection, transport and storage of wood waste takes up a large volume due to the irregularity and lack of uniformity in the shape and structure of wood waste, which makes the management process of this type of waste more expensive and difficult. Another major issue related to wood waste management is preservative-treated wood in the waste stream, which is hazardous and requires a separate management process for recovery. This hazardous waste makes the classification and recycling more difficult (Jahan, 2022).

Most of the studies found in the literature perform a life cycle analysis that considers only the environmental aspect. Furthermore, most studies consider greenhouse gas emissions but do not consider the rest of the environmental impacts, such as the extraction of raw materials, water pollution, etc. The economic and social aspects should also be considered to provide a more complete and realistic perspective. Each dimension must be analysed when developing or improving a product or process to meet sustainability criteria. LCSA supports the identification of trade-offs between dimensions and enables better decision-making in policy and industry. Moreover, some researchers argue in their studies that the use of waste materials sometimes generates additional costs due to waste management, availability and transportation, as well as complex treatment processes. Therefore, studies must expand the optimisation of these processes to balance the environmental benefits and cost reduction of these materials (Sandanaya, 2020).

4. Conclusions

This paper presented a review of the published scientific literature related to the application of residual materials in the construction sector. Through the analysis of 280 research papers published during the period 2015 and 2023 the main trends in the construction sector and the main issues that must be addressed to promote the circular economy and increase the use of residual raw materials were identified. A total of 35 articles were analysed to achieve the purpose of the paper and answer the questions initially posed. On the other hand, researchers must continue analysing waste materials in the construction and evaluating with the aim of decreasing in a near future the use of raw materials, decreasing the generation of waste and promoting the circular economy in the construction sector. Furthermore, it is important to take into account the environmental impacts but also the economic and social impacts surrounding them in the construction sector.

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