Material Passports for the End-of-Life Stage of Buildings: A Systematic Review of Benefits & Challenges

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Abstract

In many parts of the world, the construction industry is dominated by a linear economy, in which "take-make-waste" generates an alarming amount of construction and demolition waste (CDW). On the other hand, circular economy advocates for reintroducing CDW into the material flow as secondary materials. To aid this practice, building material passports were introduced as a comprehensive information database for buildings that facilitate the distribution of information across all stakeholders of the project. In this paper, a systematic review of the literature surrounding material passport development was conducted. First, this paper presents a bibliometric analysis of the recent trends in material passport research and related topics. Second, circular economy practices that benefit from implementing material passports were identified and discussed. Third, the benefits and challenges of implementing material passports were also identified and categorized. These findings are insightful for circular economy practitioners interested in learning about the latest development in material passport research and its relation to other circular economy practices.

Keywords

Material passports, circular economy, end-of-life, building construction, material re-use, construction & demolition waste management

1. Introduction

The construction industry is one of the major sectors that contribute to global energy use and waste production. The current construction practices worldwide support an unsustainable development path for the global economy. According to United Nations records, the global urbanization rate has reached 55% in 2019 and is expected to reach 68% by the year 2050 according to Aslam et al. (2020), which means a huge amount of construction projects will take place, hence more waste generation by the end of life of these projects. In 2017, the amount of waste due to construction and demolition in the US alone was estimated as 569 million tons based on Aslam et al. (2020), which shows how critical the construction waste issue and the urgent need for a strategy to manage the generated waste. CDW have significant impacts on the environment. In fact, this type of waste is either disposed in landfills or by incineration. Disposal by landfill only serves as short-term solution of CDW, as landfill negatively impact the soil it covers and space will run out eventually (Chen et al., 2021). In addition, the existence of this waste in landfills contributes to land and air pollution. It can also contaminate ground and surface water as toxic chemicals transfer through leachate (Chen et al., 2021).

The amount of extracted raw and natural resources used in construction projects is significant, and building materials at the end-of-life (EoL) stage are more likely to get disposed rather than recycled or reused (Benachio et al., 2020). Circular economy (CE) aims to keep materials and products circulating in the economy through reuse, remanufacturing, and recycling after buildings reach the EoL stage. However, the concept is not widely adopted in the industry. Material passports (MP) are an information management tool developed to boost recycling potential, enhance material recovery, and optimize the design process as cited by Soman et al. (2022). This paper reviews the recent literature on material passports, their role in facilitating circular economy practices, and their benefits and challenges. Use fewer primary resources, maintain the highest value of materials and products, and change utilization patterns.

Materials used in construction are usually tracked and verified until they are installed. After becoming part of a building, the tracking of materials is considered unnecessary, as their primary use has been fulfilled. A material passport is a digital comprehensive database for all building material information of a specific building that gives the materials of a building traceable identities (Honic et al., 2019). By giving the material an identity, MPs allow a shift in mindset towards CDW as secondary building materials rather than disposable waste, thus creating a market for re-use and an incentive for suppliers to manufacture sustainable and resilient material. Most importantly, MPs facilitate circular economy practices at the end-of-life stage of the building (Munaro et al., 2019).

Material passports are one of the sustainable development tools that promote the reuse and recycling of building materials and achieve circular economy instead of the take-make-waste system. A material passport is a digital data set that shows all the components and materials used in a built structure as explained by (Benachio et al., 2020). Using material passports by the end of life of buildings makes it easier to recovering materials instead of disposal. In addition, the value of a building material is preserved throughout the project's lifecycle and the potential of reusing or recycling it is increased. This can also eliminate any costs associated to the transportation and production of new building material, and material passports exist in different types; excel sheets are example of material passports. It can also be in the shape of online platform or a 3-D detailed model that shows all materials in a certain building (Soman et al., 2022). Moreover, material passports contain different types of material information in a high level of detail. This helps clients to have a clearer view of what a building consists of in terms of the economic and environmental values. Furthermore, some of the information listed in a material passport are place of origin, market price, supplier, after-construction condition, and the environmental impact (Soman et al., 2022).

2. Methodology

Three research questions were formulated for this review, and qualitative secondary data from peer-reviewed journal articles were used to answer them. The research questions were as follows: (1) "How do material passports facilitate circular economy practices at the end-of life stage of buildings?", (2) "What are the benefits of implementing material passports in the construction industry?", and (3) "What are the challenges involved in adopting material passports in the construction industry?" The screening process was limited to Scopus, due to its compatible with VOS viewer. The search was limited to scholarly sources published in English between 2015 and 2022. Selecting the articles involved a 4-step filtering process, illustrated in Figure 1. First, the keyword combinations used were "building construction AND circular economy", "building construction AND material passport", and "building construction AND material stocks". A total of 109 articles were found. Second, 6 duplicates were removed. Third, the remaining articles underwent abstract screening to eliminate articles not within the scope of this review, narrowing it down to 52 articles. Finally, in-depth reading was conducted based on the content of the articles. After this step, the number of articles remaining was 37 articles. Regarding the bibliometric analysis, VOS viewer was used to identify the trends in publication rate, keyword co-occurrence, and leading countries in material passport research. Afterwards, a discussion of the reviewed papers is presented, where the benefits and challenges are discussed and categorized.

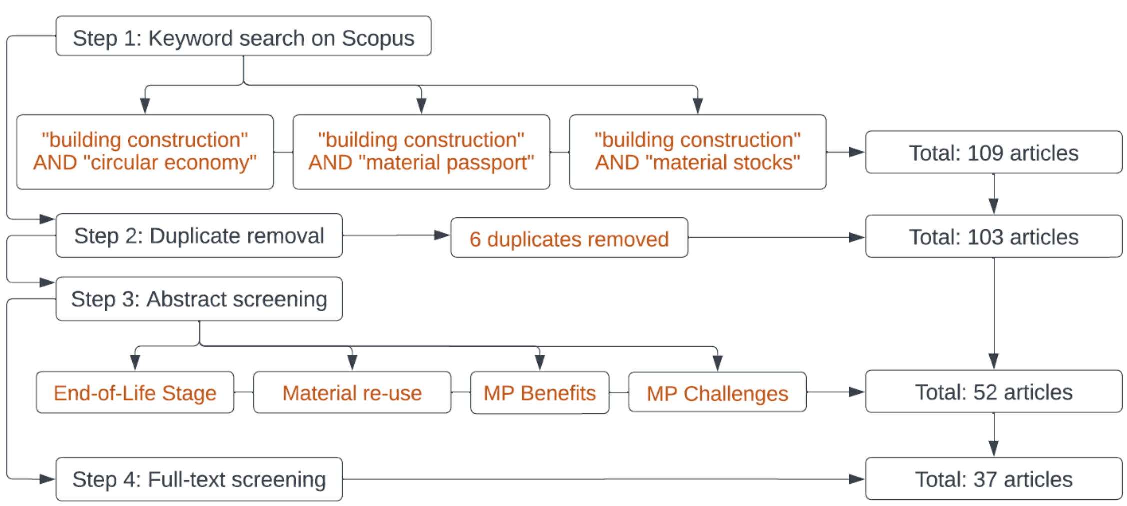

Fig. 1. Article selection process

3. Results

This section presents the results of the bibliometric analysis, which was the first step to answering the first research question.

Fig. 2(a) shows the leading publishing countries represented in the bibliometric network. Austria leads in publications for material passports, followed by the United Kingdom, Netherlands, and Spain. Fig. 2(b) illustrates the distribution of the most frequently used keywords over 97 articles in the bibliometric network. The top 5 keywords identified from the literature were: circular economy, building construction, construction industry, sustainable development, and environmental impact. The newest trends were in: demolition, planning, economic analysis, and material flow analysis.

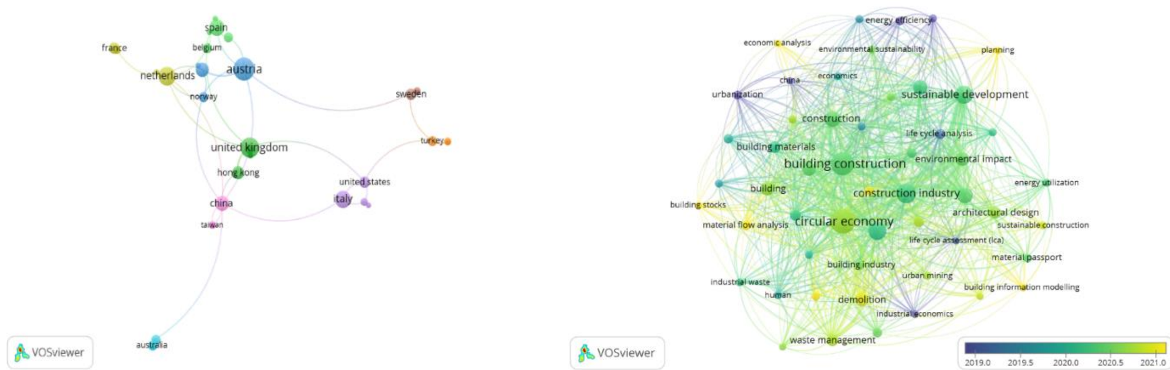

Fig. 2. (a) Bibliometric network of the countries, (b) Bibliometric network of the keyword

Fig. 3 shows the number of published articles over the past 7 years from 2015 to 2022. From 2015 to 2018, the number of published articles did not exceed 5 publications per year. However, the graph shows significant growth since 2018 and is likely to continue increasing in terms of the number of publications.

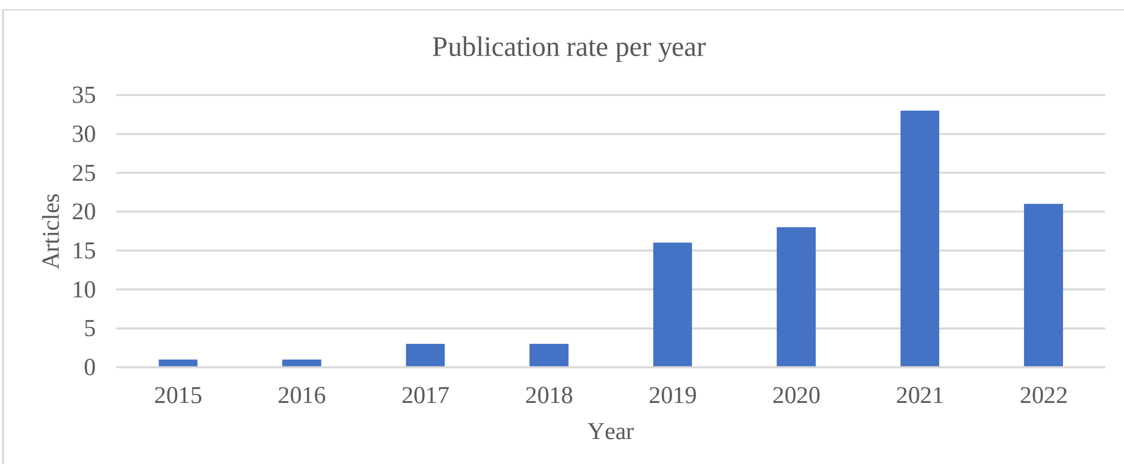

Fig. 3. Bar chart of publication rate per year for material passports

In Table 1, the previous literature was reviewed and categorized according to three main CE practices at the EoL stage.

Table 1. Thematic analysis of keywords

Theme	Articles	Total
Material Passports	(Caldas et al., 2022; Oluleye et al., 2022; Pronk et al., 2022; González et al., 2021; O'Grady et al., 2021; Rakhsan et al. 2020; Augiseau & Kim., 2021; Bertin et al., 2020; Nordby, 2019; Smeets et al., 2019; Hopkinson et al., 2019; Çetin et al., 2022; Zhang et al., 2021; Honic et al., 2021; Rahla et al., 2021; Li & Wang, 2021; Talla & Mcllwaine, 2022; Çetin et al., 2021; Almusaed et al., 2020; Schützenhofer et al., 2020; Kovacic et al., 2020; Honic et al., 2019c)	22

Material Re-use	(Munaro et al., 2019; Caldas et al., 2022; Smeets et al., 2019; Munaro & Tavares, 2021; Honic et al., 2019b; Atta et al., 2021; Çetin et al., 2022; Zhang et al., 2021; Honic et al., 2021; Rahla et al., 2021; Li & Wang, 2021; Talla & Mcllwaine, 2022; Kovacic & Honic, 2021; Çetin et al., 2021; Almusaed et al., 2020; Heisel & Rau-Oberhuber, 2020; Schützenhofer et al., 2020; Kovacic et al., 2020; Honic et al., 2019c)	18
Material Stocks	(Çetin et al., 2022; Talla & Mcllwaine, 2022; Kovacic & Honic, 2021; Çetin et al., 2021; Almusaed et al., 2020; Heisel & Rau-Oberhuber, 2020; Kovacic et al., 2020; Honic et al., 2019c)	8

4. Discussion

The following section will discuss the circular economy (CE) strategies for materials of buildings at the EoL stage, and how material passports (MPs) aid in enabling these strategies. Next, the benefits and challenges of MPs are presented.

4.1 CE practices at the EoL stage

The EoL stage of buildings is when they outlive their useful lifespans and are typically scheduled for demolition to make way for new developments. To close the material loop, Giorgi et al. (2018) define two strategies for reclaiming materials of buildings at the EoL stage: (1) Increasing the materials' lifespan through reuse, recovery, or remanufacturing, or (2) Transforming the materials into new products through recycling. The strategy chosen largely depends on the quality of salvageable materials and the purpose behind collecting that material. Oluleye et al. (2022) state that direct material reuse should be the first strategy considered, as it requires the least energy consumption, carbon emission and cost. They emphasize that this strategy is suitable for materials that preserved their high quality at the EoL stage. Recovery and recycling fulfill the same purpose of reprocessing materials into new products, but they differ in their processing method (Oluleye et al., 2022). Remanufacturing is the least used method globally, left for when other strategies are not sufficient (Oluleye et al., 2022).

Material reuse is the strategy with the lowest carbon footprint among the circular economy practices; however, there exists an unwillingness among construction stakeholders to adopt it. Adopting the material reuse strategy requires the involvement of all stakeholders in the material value chain and a thorough understanding of circular thinking in construction (Pronk et al., 2022). According to Rakhshan et al. (2020), one reason behind their uncertainty arises from the perceived high risk involved. Compliance to existing regulations and concern over health and safety are among the risks mentioned by Rakhshan et al. (2020). Thus, certain pre-requisites must be met to enable the material reuse market. The authors suggested developing standard test procedures to evaluate and certify the secondary material to improve stakeholders' perception by offering quality products. Moreover, they encouraged adopting design-for-deconstruction and training workers for deconstruction skills. Lastly, they identified the need for cheap and reliable techniques to evaluate reusability to streamline the process of certifying secondary materials.

In response, another study proposed a method to evaluate material reusability called the design for disassembly, deconstruction, and resilience index (O'Grady et al., 2021). The authors defined *deconstruction* as the removal of a building's structural elements; *disassembly* as to the removal of non-structural elements, such as wall cladding, flooring, and internal finishes; and *resilience* as the condition of reclaimed materials after being dismantled and relocated (O'Grady et al., 2021). Quality is a major concern for stakeholders when discussing material reuse, so this reusability measurement tool is a step in the right direction towards standardizing the material reuse market (O'Grady et al., 2021).

Along with measurement tools, there is a need for better documentation that can facilitate material reuse negotiations between stakeholders. The aim of a material passport is to document the material composition of a building, and this practice can improve the visibility of reusable materials in existing buildings before they are demolished. One major regional effort towards this goal was accomplished by the Buildings as Material Banks (BAMB) project, which was funded by the European Union. Spanning between 2015 and 2020, the BAMB project aimed to develop a digital platform for material passports. The project was a collaborated effort between companies, institutes, and universities located in 8 countries to create over 400 passports (i.e., 345 product passports, 7 building passports, and 76 instance passports) (Luscuere et al., 2019). A product passport includes information about a product from a manufacturer, a building passport is made up of product passports and building-specific information, and an instance passport provided more detailed information about a specific instance of a product (e.g., a specific door in a building is an instance of the generic Door product) (Luscuere et al., 2019).

In a BAMB report written by Heinrich and Lang (2019), the material passport prototype included 11 information sections: (1) Physical properties, (2) Chemical properties, (3) Biological properties, (4) Material health, (5) Unique product and system identifier, (6) Production data, (7) Location within the building, (8) Transportation, (9) Use and operation, (10) Disassembly/Reversibility, (11) Reuse and recycle. The authors identified that formatting differences may hinder efforts to create machine readable data, to introduce new users to MPs, and to standardize MPs on a wider scale. Thus, the next step is to standardize the material passport format and content needs.

Material stock analysis, like material passports, is a valuable source of information to visualize the available material stock in an area. A material stock is the sum of products, buildings, and infrastructure that stay within the economy for at least a year. The value of the material stock is in its reusability, how reliably it can be deconstructed and stored, and when it will be available in the market. Material stock analysis refers to information on location, quantity, quality, and others represented as a map of material available within a certain area (e.g., city wide, country-wide). Benachio et al. (2020) conducted a review of material stocks literature and found that city-wide assessment of material stocks based on existing buildings is possible and can benefit from further development to improve information reliability in the long term.

4.2 Benefits of Material Passports

As part of a circular economy approach at the end of life, the implementation of material passports technique in construction projects can derive various benefits. The benefits obtained from the literature are mainly categorized as environmental, social, and economic. In the long-term, the utilization of material passports promotes the reuse and recycling of construction materials and building components by the end of their lifecycle. In the short-term, material passports can provide the relevant information on various aspects of the building project to different stakeholders throughout the project life. This efficient access to information can reduce the expensive deconstruction mistakes and construction schedules (Blengini, 2009). Moreover, it can also ease the cooperation between stakeholders and increase the traceability of materials used in a certain project. In addition, it can potentially preserve or increase the value of building components as reusable or recyclable material by the EoL stage (Blengini, 2009). This can also reduce CDW which saves costs and reduces harm on environment.

First, in terms of the environmental impact, it was found out that the integration of circular economy practices by the end of life of construction projects reduces the demand on natural and raw resources. It also eliminates the long haulage process of the new resources from their origin to factories (Silva et al., 2019). This saves huge amounts of CO_2 emissions which is eventually beneficial to the environment. In addition, according to Minunno et al., a modular purpose-built prototype was designed and built-in order to assess the environmental benefits of reusing materials (2020). The project under the name of Legacy Living Lab (L3) was designed for disassembly by the EoL stage. The purpose of material passports utilization is to provide a wide understanding about how the materials can resulted from disassembly be recycled or reused in order to be used in a new building. The L3 project has undergone a lifecycle assessment in order to define what environmental benefits it has brought. It was found out that the implementation of a circular economy practice at the end of life saved around 87% of the total embodied energy (Minunno et al., 2020). In other words, if the L3 was built as a linear model it would have resulted in 5460 megajoules (MJ) embodied energy. However, since the model was built as a CE it has only embodied around 750 MJ. In addition, the circular L3 has shown a significant decrease in the global warming potential. This reduction was estimated at around 28% when compared to the global warming potential resulting from conventional or linear models (Minunno et al., 2020). In addition, the proper management of buildings' components at the end of life avoids landfilling the demolished waste. This will result in providing more capacities in landfills and reducing the demand on waste dumps, and hence saving more land areas. This achieves sustainability goals since land has become a scarce source and has to be preserved.

Second, the use of circular economy practices at the end of life of construction projects can be economically beneficial. This is because it can save huge amounts of costs that are mainly wasted upon eliminating the danger of collected waste that impacts human health (Marzouk et al., 2014). For example, a simulation was designed in Egypt in 2014 in order to predict the difference in waste amounts in case circular economy practices are adopted at the end of life of projects. It was found out that the adoption of circular economy practices can eliminate costs that are incurred by the government annually (Marzouk et al., 2014). These costs are mainly associated with the expenses of mitigating the damage caused by emissions and air pollution which are resulted from demolition waste and impacts human health, costs of reducing the harm of collected waste that impacts the surrounding environment, and costs that are spent on designing and building new landfills and waste dumps (Marzouk et al., 2014). According to the simulation, the proposed cost eliminations are significant. For example, in Egypt, the unit cost of constructing small, medium, and large landfills is 165.58 $\$/m^3$, 99.29 $\$/m^3$, 66.29 and $\$/m^3$, respectively. In addition, costs required to mitigate air and land pollution are estimated as $16,161.35 billion over a period of 20 years (Marzouk et al., 2014). In fact, the integration of circular economy practices at end of life which involves reusing and recycling materials would eliminate most of the listed costs and disburden these amounts from the government. This proves the importance of financial benefits of the circular economy.

Third, social benefits can also be obtained through the implementation of material passports. The social aspect shares the same importance with the economic and environmental profile of circular economy since it is one of the sustainability pillars. The paradigm shifts into sustainable systems that was proposed by several studies involves the reduction of impact on human health (Minunno et al., 2020) and (Marzouk et al., 2014). In fact, the conventional approach to manage buildings' materials and components by the end of life imposes high risk on human health. The utilization of material passports which encourages the reuse of materials is an enabler to control the rising amounts of pollution and waste that impacts air and land and eventually threatens human welfare and wellbeing (Wijkman et al., 2015). In addition, it is expected that the extensive transition to circular economy practices can provide new jobs in the market and reduce unemployment rates. This is because practitioners have to be well prepared and trained to deal with technologies such as material passports (Wijkman et al., 2015).

Table 2 summarizes the thematic analysis of the benefits identified from the literature; the benefits are categorized into three categories based on the sustainability pillars as mentioned in literature. It is clearly indicated that most of the studies focused on the environmental benefits of MP and very few highlighted the social benefits on human health and well-being.

Table 2. Thematic Distribution of MP Benefits

Category	Article	Total
Environmental	(Benachio et al., 2020; Blengini, 2009; Silva et al., 2019; Marzouk et al., 2014; Li & Wang, 2021)	6
Economic	(Silva et al., 2019; Marzouk et al., 2014; Li & Wang, 2021)	3
Social	(Silva et al., 2019; Wijkman et al., 2015)	2

4.3 Challenges of Material Passports

Technical challenges in implementing material passports were highlighted in several studies (Nordby, 2019; Munaro & Tavares, 2021; Çetin et al., 2022; Zhang et al., 2021). Nordby (2019) stated that the technical, is due to deficiency of information about used construction materials that will be likely to attain in other project, which makes this practice not effectual to be executed. Additionally, Honic et al (2021) highlights the same issue while integrating building information modelling (BIM) and MP. Another study by Çetin et al. (2022) highlighted the challenges of implementing material passport, based on interviews conducted with experts, revealed that MP challenges are technological, regulatory and market challenges. Technological challenges were also presented, such as lack of data management mechanisms, high costs of implementing digital technologies into material passport practice, and lack of technological integration. Lack of data management mechanisms; in the sense that this material might last for 50-80 years, considering the lifetimes of the material (Zhang et al., 2021), such as foamed concrete 50 years, exterior wall paint 35 years, and mortar 75 years, which necessitates the material information in the passport is dynamic to reflect the status of the material over time. High costs of implementing digital technologies into material passport practice, since implementing material passport will require a lot of technology adoption into the field, which will be expensive. Lack of technological integration; in which to have an effective material passport implementation, we should integrate the practice with technology tool, such as building information modelling (BIM), however, the lag of this integration is causing MP to be impractical. Moreover, the volume of data generated from MP is enormous, in which each material embedded in a building should be fully described, this huge amount of data needs to be stored safely for a long period of time, which makes this a serious challenge (Munaro & Tavares, 2021).

Market challenges are defined by the lack of viable business models. Practical models for MPs exist; however, they are not fully automated to update over time, resulting in outdated data (Çetin et al., 2022). Additionally, Nordby (2019) calls it an undeveloped market, as it will be a challenge for professional practice to execute, due to the lack economic driving influence. Due to added time required for engineering and demolition, uncertainty around documentation, and additional expense, a construction process using reused materials becomes complicated and expensive.

The regulatory challenge is due to the lack of regulations and framework for selling and utilizing used materials in in new building; also referred to as organizational challenge (Nordby, 2019). Additionally, Almusaed et al. (2021) emphasized on the fact that the lack of technical regulations is one of the most contributing barriers. Another study defines the regulatory challenge, is the lack of regulations for material reuse in terms of standards that encourage the reuse practice (Çetin et al., 2022; Sigrid Nordby, 2019).

The political challenges are divided into four main categories based on Munaro & Tavares (2021) and Munaro et al., (2019), including the complexity and fragmentation of the construction supply chain, causing an increase of material waste and cost of projects, and risk the project due date. The second challenge is conflicting environmental and energy policy measures; in which if we prioritized high-energy performance buildings, this would encourage the usage of materials that are not suitable to deconstruction and reuse. Furthermore, lack of standardizing project data, in which identifying the reuse potential materials might be impossible since not enough data is provided. Additionally, the lack of certification and quality assurance for recycled materials is also a political challenge.cc

Since MPs are presented in different levels, starting from broader to more specific, building, system, component, and material (Zhang et al., 2021), identifying and separating materials and products to maintain quality is a challenge. Studies by Munaro & Tavares (2021) and Munaro et al. (2019) refer to it by complexity of materials/ systems/ components. Additionally, longevity of buildings and infrastructures is another commercial challenge in which there is a different lifecycles and maintenance required for buildings, and the components, for this specific information should be highlighted in the MP. Moreover, suppliers usually refuse to provide information that would expose their business, creating another challenge to collect data required in the material passport. Munaro & Tavares (2021) and Munaro et al. (2019) refer to this challenge as intellectual property concerns. Not only suppliers might cause a challenge in implementing MP practice, but also stakeholders might, in which their commitment is very essential to providing reliable data for material to be reused. This challenge is also indicated as collection and release of reliable data, and after getting this data it should be continually updated and should present the current state of materials embedded. Thus, constant data and information updating is also a challenge (Munaro et al., 2019; Munaro & Tavares, 2021). Studies have highlighted the importance of stakeholder's engagement implementing MP practice. Smeets et al. (2019) believe that MPs cannot be fully utilized without the stakeholder's engagement. Similarly, Rahla et al. (2021) believe that stakeholder involvement is one of the barriers hindering the adoption of MP, since when stakeholders monitor, identify, and assess material, more quality assurance will take place of recycled materials to match supply with demand. The incorporation of sensors into materials is the last challenge, in which plugging sensors in the material, will provide the current state of it and real-time data, which can also be a challenge to execute (Munaro & Tavares, 2021; Munaro et al., 2019).

Finally, the social challenges are divided into three sub-categories based on Munaro & Tavares (2021)and Munaro et al. (2019). Reversible design can reduce long-term costs; however, it requires a high capital cost. For that, estimated savings in reversible design is inaccurate, which is considered a social challenge hindering the adoption of MP practice. Another challenge is that people are not aware of flexible buildings and the concept is not well known, due to the lack of protocols for owners and users. Finally, the existence of other construction practices is prioritized, such as safety and energy efficiency.

Table 3 summarizes the thematic analysis of the MP challenges discussed above.

Table 3. Thematic analysis of MP challenges

Category	Details / Subcategories	Sources
Technical	• The lack of data management mechanisms • Lack of technological integration • Deficiency of information about used construction materials • The lack of storage network	(Nordby, 2019; Munaro & Tavares, 2021; Çetin et al., 2022; Zhang et al., 2021; Honic et al., 2021)
Market	• Lack of viable business model • Undeveloped market • Lack of economic driving influence	(Nordby, 2019; Çetin et al., 2022)
Regulatory	• Lack of framework for selling and utilizing used materials • Lack of technical regulations • Lack of standards for material reuse	(Nordby, 2019; Çetin et al., 2022; Rahla et al., 2021)

Political	• Complexity and fragmentation of the construction supply chain • Conflicting environmental and energy policy measures • Lack of standardized project data • Lack of certification and quality assurance for recycled materials	(Munaro et al., 2019; Munaro & Tavares, 2021)
Commercial	• Complexity of material and systems in the construction industry • Longevity of buildings and infrastructures • Intellectual property of materials • Lack of stakeholder's engagement	(Munaro et al., 2019; Smeets et al., 2019; Munaro & Tavares, 2021; Li & Wang, 2021)
Social	• High initial capital cost • Lack of awareness, stakeholder hesitation • Lack of priority	(Munaro et al., 2019; Munaro & Tavares, 2021)

5. Conclusions

The increasing rates of urbanization and building demolition create significant amounts of waste that have long-lasting effects on the environment. To answer this review's research questions, qualitative secondary data from peer-reviewed journal articles were extracted using the Scopus database. Four circular economy practices were identified for the end-of-life stage of construction projects facilitated by the use of material passports. In addition, the benefits and challenges of implementing material passports in the construction industry were investigated. The unique value of this review paper is its focus on the EoL stage, whereas previous review papers focused on the CE practices at the design and construction stages. Moreover, the development of material passports received new advancements in recent years that had not been reviewed. Subsequent paragraphs, however, are indented (here insert the second paragraph).

The four main CE strategies for handling CDW are reuse, recycling, remanufacturing, and recovery. Reuse requires the least energy consumption, carbon footprint and cost, but there is a prevalent unwillingness among stakeholders to adopt this practice. However, efforts have been made in recent years to combat the stigma associated with reusing building materials, and the prerequisites for it were discussed. The implementation of material passports has indirect positive impacts on the environment, economy, and society. Significant reduction to CO_2 emissions, reduced demand on raw materials, and reduced demand for landfills are among the top environmental incentives. Moreover, major cost reductions can be achieved from using secondary building materials. From a social perspective, the benefits included reducing the impact of pollution on human health and creating new jobs related to material passport development and extending the material supply chain to the material reuse market. Challenges extracted from literature were categorized into technical, market, regulatory, political, commercial, and social. The technical challenges were the main focus of previous studies, but these challenges stem from a general lack of priority or engagement of construction stakeholders who are not familiar with circular economy practices.

Lastly, the research gaps should be mentioned for future researchers to consider. The current state of the literature showed more concern for the challenges rather than the benefits, which reflect that material passports are still in the early stages of maturity in circular construction research. For future work, more implementation studies are needed to continue experimenting with material passports and their usability. Subsequently, the social benefits may become more apparent with more implementation studies carried out. Similarly, a closer look at the challenges is warranted to understand the milestones needed to overcome them. One of these milestones that could be explored is finding the means to measure the circularity of building materials. Overall, these findings are insightful for circular economy practitioners interested in learning about the latest development in material passport research and its relation to other circular economy practices.

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