Towards a Circular Building Industry

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Abstract

The building industry has a major environmental impact in terms of global energy use, carbon emissions, resource use, and the production of waste. To reach ambitious international environmental goals, the building industry faces a need for large-scale change. Circular strategies for buildings include using building and materials longer through lifetime extension strategies, reuse, sharing, renovating, refurbishing, and eventually deconstructing and recycling materials. The chapter presents many specific examples of these strategies in practice. Policies are also a key driver of circularity in the building and construction industry and an overview of the policy mix is discussed with examples from the EU, which has implemented many such policies targeting the building and construction industry

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in particular. While there are many positive examples of circularity in the sectors, there remain challenges, and changes are needed. Regulations regarding development and demolition plans, waste, and use of buildings need to be fundamentally reconsidered in order to further enable and encourage circularity in this sector. Barriers in the reuse and market for reusable building components and materials need to be addressed. There is a need for a shift in thinking in the industry to enable the normalization of circular business models and practices. Future trends in digitalization and policies promise to further push for a more circular building sector.

Keywords

Circular economy · Building · Construction · Recycling · Reuse · Deconstruction

1 Introduction

The building and construction industry is a major contributor to global energy use, global carbon emissions, use of materials, and production of waste. In 2020, 36% of final energy consumption and 37% of energy-related CO_2 emissions globally were attributed to the sector (United Nations Environment Programme 2021). To reach global sustainable development goals, the building industry is facing a need for change on a large-scale, including all parts of a construction life cycle. One important aspect is to decrease the energy use during the operational phase of a building. Many governments around the world have implemented policies such as energy-efficient measures and stricter limits on energy use for new buildings, and this sector is mentioned in 136 nationally determined contributions pursuant to the Paris Agreement. However, while efficiencies improve and emissions intensities decrease, gross building area continues to increase and material use is projected still to rise significantly in the building and construction sector (United Nations Environment Programme 2021). Energy efficiency is not enough.

While a significant amount of the greenhouse gas emissions are associated with the use of energy in the building during its operation, embodied emissions, i.e. the emissions in the materials themselves, are currently projected to be half of the emissions in newly constructed buildings (United Nations Environment Programme 2021). Embodied emissions have been rising in recent years and are projected to significantly increase with construction and renovation, meeting higher energy efficiency standards (IEA 2020; Architecture 2030). In some countries with ambitious building regulations and low-carbon-intensity electricity, such as the Nordic countries, embodied carbon emissions for buildings can be several times greater than the emissions associated with operational energy use (Zimmermann et al. 2021).

Many construction materials need a significant amount of energy for their production, e.g. cement, steel, and glass. The carbon emissions from producing these materials are also extensive. Looking at the production of Portland cement, it requires temperatures about 1400 °C, which means high energy consumption, resulting in a significant part of the world's carbon dioxide emissions. Roughly, cement production accounts for at least 7–8% of all emissions from industry and the energy sector (Architecture 2030). As part of the transition to low-carbon economies and societies, a strategy to reduce embedded energy in the building sector is needed.

Beyond the energy intensity of building materials, there is also the material intensity of the sector to consider. In 2019, 100.6 billion tonnes of materials were consumed globally, of which 38.8 billion tonnes were used in the housing sector (Circle Economy 2020). A large fraction of the material used in the building and construction sector eventually becomes waste. Construction and demolition waste (CDW) is the largest waste stream worldwide (estimated to be 30–40% of total solid waste) (López Ruiz et al. 2020). It is estimated that 374 million tonnes of CDW were generated in the EU in 2016, excluding excavated soil (Wahlström et al. 2020). In 2018, approximately 4.5 million tonnes of CDW were produced in South Africa (Department of Environmental Affairs 2018), 2.36 billion tonnes in China (Ginga et al. 2020) and 600 million tonnes in the USA (US EPA 2018). Much of CDW is currently disposed of in landfills, with an estimate of only 20–30% of it recovered globally (López Ruiz et al. 2020).

Even when recycled, waste fractions are often significantly downcycled, e.g., concrete and masonry used as filler material for roads or building construction (Durmisevic et al. 2016). Only a very small fraction is reused, e.g., reclaimed clay bricks and tiles (Debacker and Manshoven 2016). There is clearly more that can be done to retain the value of these materials.

Globally, there is also increased policy focus on the need for greater resource efficiency in the construction sector, which has been deemed by UN institutions as a critical sector for achieving sustainable development goal (SDG) 12: sustainable consumption and production. "Sustainable Buildings and Construction" is one of the six focus programs of the One Planet network, which was formed to implement the 10-Year Framework of Programmes to support the achievement of SDG12. In dealing with the entire lifecycle of carbon emissions in the building industry, Europe is considered one of the leading regions (United Nations Environment Programme 2021). The focus of the program in 2021–2022 is on circularity. The construction sector is also a priority sector in the European Commission's circular economy action plan (EU Commission 2020) and there have already been EU-funded research projects investigating the potential for more circularity in the building industry.

Some countries have also made circularity goal, for example, the Netherlands has a goal to be 100% circular in 2050. The influence of the goal is evident not only on the national level but also on the city-level. For example, the city of Amsterdam has developed a circular strategy based on the doughnut model (Raworth 2017), describing how actors can contribute to economic development and well-being while still respecting the limits of the planet. As a result of this circular strategy, many building projects are developed focusing on circularity in major focus and the Netherlands is considered a leader in circular knowledge in the building industry (Kanters 2020).

Following policy and societal objectives, there is an increased focus on research investigating the potential benefits of integrating circular economy (CE) principles and applying CE strategies in building construction (Hossain and Ng 2018). This presents a great opportunity for the building industry to further sustainable development goals and it is now widely discussed how the building industry could move toward a circular economy in practice.

2 Increasing Circularity

Looking at circular economy in the building sector, there are many different circular strategies that can be applied (Fig. 1). Circular strategies can be applied to extend the lifetime of a building through design choices, but also in repair and maintenance during the use stage. Beyond its initial use, the building can be reused, shared, and repurposed to enable longer or more efficient use. Buildings can be renovated and refurbished to enable further use. At the end of use, buildings can be deconstructed to enable greater reuse of materials and components, and even remanufacturing of building components. Lastly, building materials can be recycled to recover the raw materials. Utilizing these strategies can minimize the environmental impacts of different lifecycle stages of a building and ensure that buildings are not simply wasted at their end-of-life, but instead the materials are recycled back into product lifecycles. In reality, not all strategies are utilized for all buildings and these strategies become complex when considering the building, component, and material levels together. Complexity only increases when considering energy resources in addition to material resources. In addition, there can be different definitions, overlap

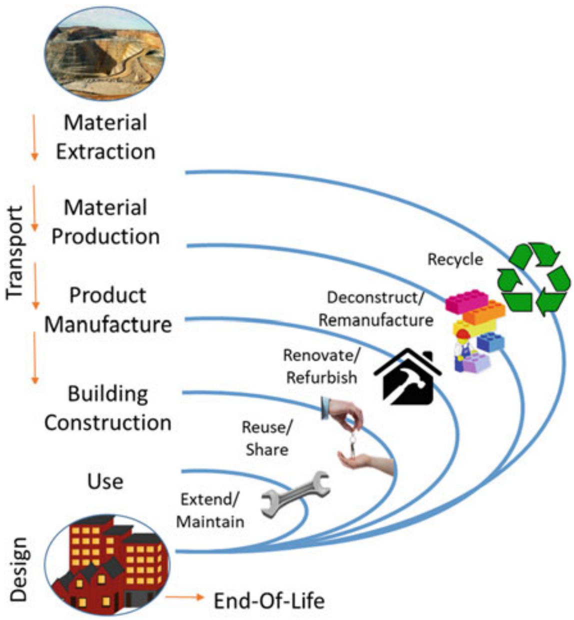

Fig. 1 Lifecycle stages and circular strategies. Generally, the inner loops with the purpose of sharing, extending, and maintaining focus on keeping the existing building intact and extending its lifetime with minimal new material and components. Each loop generally increases the complexity of the strategy and the changes made to the existing building to the final outer loop, where only the building's materials are cycled back into production systems

of the terms used, and additional terms that could describe circular strategies, e.g. restoration, retrofitting, adapting, remodeling, and repurposing.

2.1 Applying Circular Strategies

In applying circular strategies in the building and construction sector, it is important to consider the building as a complex "product" with several layers, including the facade, structure, and inner furnishings (Brand 1995). A building is also a product containing other products, and each of these products also has its own lifecycle within the whole of the building system and its own expected lifetime in relation to the building itself – see Fig. 1 (Pomponi and Moncaster 2017).

As seen in Fig. 2, the structure of buildings can have a very long technical lifetime. While building codes might indicate minimum service life for design, like other products, lifetime in practice can be more complex than the technically designed lifetime. Actual building lifetimes depend on factors such as the environment in which it is built, how the building is used and maintained, and the needs of its users and owners. This results in much variance and uncertainty about the lifetime of buildings. For example, the Minnesota Demolition Survey of buildings between 2000 and 2003 found that of 227 buildings 6% were demolished at 0–25, 23% were demolished within 25–50 years, and only 16% of the commercial buildings were demolished due to the physical condition of the building (Trusty and Argeles 2005). Another study of building in Finland looked at 50,818 buildings demolished between 2000 and 2012 (Huuhka and Lahdensivu 2016). The study found that

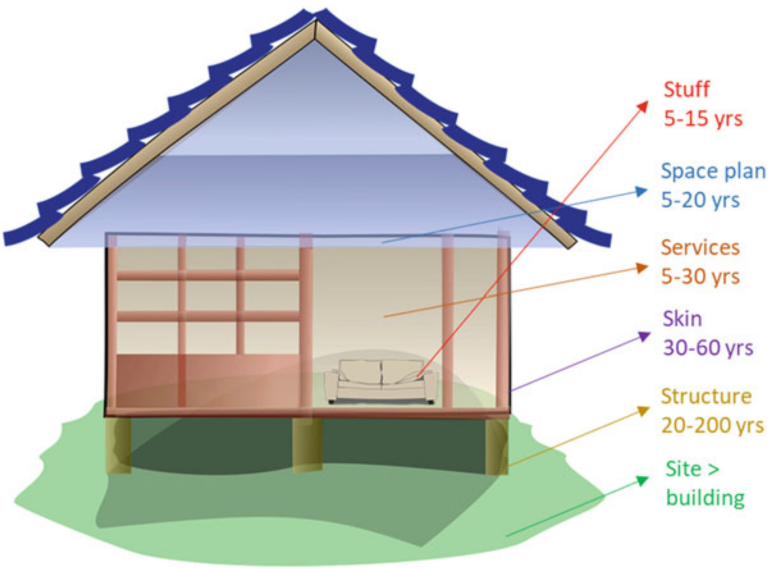

Fig. 2 Layers of a building can have different technical and functional lifetimes

while lifetimes of detached houses and blocks of flats averaged 60 years, non-domestic buildings had typical lifetimes of less than 40 years and were not demolished because of the condition of the building.

There indicates significant potential for extending the useful lifetime for non-residential buildings in particular and longer building lifetimes can have environmental benefits. Marsh (2017) studied the environmental impacts of building components in relation to building lifespans of 50, 80, 100, and 120 years in a Danish context. The results indicated that, compared to a building lifespan of 50 years, a building lifespan of 80 years can reduce the overall environmental impacts by 29% and even longer lifetimes can further reduce impacts.

2.1.1 Extending Building Lifetimes

Designing for longer lifetimes can start with designing with durable materials that consider the needs of the users. In 2015 devastating earthquakes left thousands of people homeless in and around Kathmandu, Nepal. This required massive rebuilding of homes, but also an opportunity to build more durable housing that could better withstand future earthquakes by learning from the structures that performed well in the 2015 earthquake. A decentralized approach was promoted by an organization called ABARI, which helped individual homeowners build and construct their own housing with free Open-Source design handbooks. The techniques used rammed earth as a primary material with bamboo and wooden studs used in the roofing (One Planet Network 2021a).

Extension of lifetime also requires maintenance of structures, components, and materials. The possibility to maintain a product or a component within a building has been de-prioritized by the building industry (Huuhka and Vestergaard 2019). It has often been more cost-efficient to remove an old product and change to a new one, rather than maintain an existing product. The market has adapted to this by selling products that are easy to change but difficult to maintain, often marketed as maintenance-free. This is slowly changing due to higher commodity prices but also changes in policies (which we explore in more depth in the next section). By putting explicit demands on possibilities for maintenance in procurement, local communities and companies can take action for increasing the possibilities of maintainable products in the building industry.

Figure 2 highlights that extending the lifetime of a building also involves addressing its many layers within the structure and their interactions. There can be differences between the lifespans of the building, its components, and the materials in the components. The lifetime of the materials and its placement in the construction needs to be considered when planning the building and the plan for maintenance, with no waste generated. Strategies for life extension need to go beyond material selection and design for durability, but also adaptability for lifetime extension and reuse (Trusty and Argeles 2005).

Enabling a longer lifetime in design involves adaptable structures. The USC Cinematic Arts building in LA is considered a unique example of an owner demanding a 100-year lifetime for the building. Building this to meet the earthquake-prone California building codes required designing the structure with flexible joints that could fail in an earthquake and be replaced. This design protected the main structural elements and enabled easy repair while exceeding the building code requirements. It is an example of thinking about the lifetime of different layers and designing flexibility to separate layers and components when needed.

Adaptability of the layers also refers to the use of the building and enabling different users with changing needs over the course of its lifetime. Many commercial buildings are already regularly adapted to new tenants, usually with a change in the most inner layer of the building construction, building installations, and furniture. Upscaling this practice is seeing business model innovation, including more modularity and adaptability of layers like wall frames (see, e.g., Finch et al. 2018) or even leasing of the shorter-lifetime layers of building (Leising et al. 2018).

2.1.2 Sharing

Sharing in the context of the building sector can be considered from different perspectives. Rental of tools is a well-functioning business and an excellent example of sharing. It is also becoming more common to include functions within the developed product to ease sharing between users, such as clothing libraries, bike- and carpools, and common spaces.

Another way to share spaces is to have multiple activities in one building during different hours of the day, as described by Kyrö (2020). Occupancy level was measured in schools finding an annual occupancy level of around 5%, showing a huge potential (Johansson and Bagge 2012). This strategy is, in turn, enabled by buildings designed to be adaptable for multiple building uses. For example, furnishing and equipment can be leased with a product as a service business model that enables such adaptability and reuse of these components (Öhgren et al. 2019).

2.1.3 Reuse

Materials from carefully deconstructed buildings can be reused. Also materials and components that are left over or the result of purchasing errors can be used rather than disposed – these can be catalogued and shared, both between sites within the same company and between different companies. Examples of such materials include unopened packages of insulation, inner doors, and gypsum boards. Kristian Augusts Gate in Oslo, Norway, a building from the 1950s, was renovated using material from nearby building projects that were incorrectly ordered or removed during renovation. Materials from the original building were also reused within the project. Steel, concrete slabs, and bricks are examples of loadbearing materials that were reused from the original building while cooling baffles, façade material, and tiles in the bathroom interior were reused from other projects.

2.1.4 Renovation

Renovating buildings including energy efficiency measures both extends the life of a building and reduces the energy demand for space heating, cooling, and electricity. Energy use during a building's operational phase has a major impact on the global total energy use (IEA 2020). Much research is done within this field since the need of decreasing the energy use in buildings has been in major focus for many years. Most focus has been only to improve the energy performance of the building, but in the last years, there has also been extensive research on transdisciplinary sustainability (Mjörnell et al. 2015). Social sustainability together with economical restrictions of inhabitants makes huge energy efficiency renovations unrealistic in general. Also the aspects of heritage values mean that energy efficiency measures are a too narrow scope (Olander et al. 2019). The need for less extensive renovation measures goes hand in hand with an increasing circular economy. In future renovations, it is important to combine energy efficiency with caution regarding the use of materials. The energy efficiency measures made should be possible to disassemble and avoid damaging the existing building, e.g., moisture damage, heritage value, or indoor air quality. Optimizing for one environmental target cannot be made at the expense of another, such as changing windows in good condition instead of adding a pane of insulating glass.

Renovation with reused materials can combine circular strategies. The Norrsken Kigali House in Rwanda demonstrates that renovation can incorporate extensive materials and building reuse. Instead of demolishing the old structures built in 1968, these were maintained to extend the life span of the building. Some structures could not be maintained, but almost all the materials were either reintegrated into the design of the building or used in the landscape, which was also maintained as much as possible during the construction. The new structures were designed to be modular and assembled as a bolted system to facilitate dismantling and repurpose at the end of life (One Planet Network 2021b).

2.1.5 Design for Disassembly (DfD)

The potential for reusing materials and components depends on the way the building is treated at its end-of-life and how the end-of-life is considered in the initial design. Design for disassembly, or deconstruction, (DfD) of buildings involves designing buildings and products so that they are easy to disassemble into their individual components, so they can be more readily reused or recycled with a higher quality than mixed demolition waste. Buildings designed this way can then function as material banks, temporarily storing components and materials that can be reused in the future. This approach can significantly reduce waste, maintain the value of materials, and slow new material use (with its associated embodied emissions) (Debacker and Manshoven 2016).

There are several examples of this approach in the Netherlands. One example is the office park "Park 20|20." In this development area, the buildings and interiors are designed for disassembly; the buildings are seen as material banks and the functions of the buildings are available through leasing and functions as a service (Leising et al. 2018). One example of this is the people's pavilion in Eindhoven, built in 2017. This building was designed for disassembly and was only in use for 9 days. All materials were borrowed, and no waste was generated when disassembled.

2.2 Upcycling

The Danish Architect company Lendager Group has demonstrated projects where up-cycling of building materials has been in major focus. The Resource Rows and Upcycle studios in Copenhagen are reusing bricks and windows in new ways, where the architectural expression is included in the reuse of the materials. Another example is the Circle House in Copenhagen, Denmark, which is constructing 60 general housing units that can be assembled, disassembled, and reassembled into other buildings while maintaining economic and aesthetic values. The objective is for 90% of the materials used for the buildings to be reused in high-value applications. The Lendager group was the material consultant in another good example, the Swedish project Varvsstaden in Malmö, where an old working district was transformed into a new city district. Here, building materials such as bricks, windows, and steel are reused, where the reuse of materials not only to decreases the carbon and environmental impact from the project but also keeps the history of the area and its cultural value.

2.2.1 Deconstruction

While DfD enables disassembly, existing buildings not designed with this strategy can still be deconstructed. The success of disassembly or deconstruction is affected by many factors including the building systems and technologies used, the quality of materials, the reversibility of the connection or joining techniques, the assembly sequences, the required time, and competence for disassembly (Kanters 2018).

There are also many examples outside Europe of deconstruction and reuse. In China, the new campus of the Southern University of Science and Technology and Shenzhen University required demolishing of existing structures. The project would have generated 666,000 m^3 of CDW: concrete (30%), crushed brick (40%), unproductive soil (25%), and non-inert waste (5%), which would have cost 50 million RMB to transport. By reusing and recycling, the C&D waste on the site, the cost came down to 20 million RMB. It was estimated that this project saved about 600,000 m^3 consumption of raw materials, e.g., sand and stone (One Planet Network 2021a).

The BioHotel in Colombia applied circular strategies in the deconstruction of the building on the site and reused 70% of the materials. The project also used the excavated soil as aggregate in the building materials. The project was a success in demonstrating the feasibility of deconstruction, but also showed that this strategy is better enabled if considered in the design, not only at the end-of-life (One Planet Network 2021c).

2.2.2 Recycling

A final, but very important circular strategy is recycling, or closing the material loops to ensure that less new materials are needed in production and consumption systems. As mentioned, currently about 20–30% of C&D waste is recycled globally, with a mixed picture of performance for different countries (López Ruiz et al. 2020). The European Waste Framework Directive includes a target to reuse or recycle 70%

(by weight) of all non-hazardous national CDW. As of 2018, some member states were achieving over 90% recycling of this waste (EU Commission 2018). It is important to note, however, that there are still challenges to retaining the value of the materials in recycling – a topic explored in a later section of this chapter.

2.3 Enabling Circular Strategies

Data is also key for enabling circular strategies. Building stock and flow models cataloguing the materials in existing buildings is becoming more common. Material passports for buildings are proposed to create a digital record of specific characteristics of materials in a construction project, thereby enabling the different components and materials to be recovered, recycled, and reused (see, e.g., Heinrich and Lang 2019). Having knowledge about embedded materials can serve as a base for planned maintenance but also be used to set a full value on the real estate, including the value of the material used. It can also be used when the building is demounted, to know the content and remaining life length of a material or product. To have this knowledge and look at buildings as material banks is important to enable a circular building industry.

The Triodos Bank office building in the Netherlands has been designed with a digital passport with information about all the materials, and this, along with mechanical fixings, is anticipated to enable that every element can be disassembled and reused. Also in the Netherlands, a company collecting data for material passports is Madaster, which is working with the city of Amsterdam to inventory components of public buildings. In Copenhagen, the city is mapping all construction, building, and demolition in the city as a start of similar data gathering to enable circularity. Work on digital building passports and demonstration projects is currently part of large EU-funded research projects such as Buildings as Material Banks (BAMB) and Circular Construction in Regenerative Cities (CircuIT).

Trading platforms for building materials, together with local trading places, enable the reuse of building materials. For example, building with reused materials is a growing trend within the Nordic building industry. Most common is the trade of interior materials, where interior material for offices is now evolving from pilot projects to an everyday business. Another example of this growing market is the trading of used bricks. The next step is the reuse of load-bearing constructions, with many ongoing research projects now investigating methods and applications.

2.4 Policies Driving Circularity

The building industry is heavily regulated worldwide, but less so concerning resource efficiency and there is an important role for policies to further enable and drive circular strategies. Most resource-efficiency policy initiatives for the construction sector currently implemented are observed in the European Union (EU) and the Member States (MS), and the EU has often used a case for best practice in circular

Table 1 EU strategic policy framework, regulations, and tools influencing resource efficiency in the building sector (chronological order)

2008	Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2018 on waste (Waste Framework Directive)
2010	Europe 2020: A strategy for smart, sustainable, and inclusive growth (COM(2010) 2020 final)
2011	Roadmap to a Resource Efficient Europe (COM(2011) 571 final)
2011	Regulation (EU) no. 305/2011 of the European Parliament and of the Council of 9 March 2011 laying down harmonized conditions for the marketing of construction products and repealing Council Directive 89/106/EEC (Construction Products Regulation)
2012	Strategy for the sustainable competitiveness of the construction sector and its enterprises (COM(2012) 433 final)
2013	General Union Environment Action Programme to 2020. Living well, within the limits of our planet (Decision No 1386/2013/EU)
2014	Communication on resource efficiency opportunities in the building sector (COM(2014) 445 final)
2015	Closing the loop – an EU action plan for the Circular Economy (COM(2015) 614 final)
2016	EU Construction & Demolition Waste Management Protocol (EC, 2016)
2018	Guidelines for the waste audits before demolition and renovation works of buildings (EC, 2018)
2018	Directive (EU) 2018/851 of the European Parliament and the Council of 30 May 2018 amending Directive 2008/98/EC on waste
2019	Building sustainability performance – Level(s) (EC, 2019)
2019	The European Green Deal (COM(2019) 640 final)
2020	A new Circular Economy Action Plan for a cleaner and more competitive Europe (COM (2020) 98 final)
2020	A Renovation Wave for Europe – greening our buildings, creating jobs, improving lives (COM/2020/662 final)

building policies (United Nations Environment Programme 2021). Most policy approaches outside the EU are not specific to the construction and building sector, i.e. as part of policies broadly addressing circularity in the economy or focused on the management of waste. However, in the EU, after the introduction of the EU Circular Economy (CE) Action Plan (COM(2015) 614 final), several initiatives were materialized that regulate a variety of aspects in the lifecycle of a building, from waste prevention and design for deconstruction to waste recycling and rules for reuse of building components. Table 1 presents an overview of all the relevant policy interventions targeting the resource efficiency in buildings in the EU.

2.4.1 Construction and Demolition Waste Recycling Target and End-of-Waste Criteria

Although the wide EU resource efficiency policy framework contains policies at different life cycle phases (e.g., design, production, end-of-life), the main efforts have focused on increasing recycling to meet the 70% CDW recovery and recycling target of the Waste Framework Directive (WFD). The revised WFD (2018/851) introduces the End-of-Waste (EoW) concept and defines criteria to establish when waste ceases to be waste after recovery operations and becomes a secondary product or material. The potential "second life" of a reclaimed construction element is affected by the EoW criteria, which highlights the importance of "market" value and the existence of respective market outlets, as well as the importance of the assigned "purpose" of use – whether the reclaimed element will be used for the same purpose or not.

2.4.2 Selective Demolition

To achieve high levels of reuse and recycling of CDW, selective demolition, and separation of construction materials at the source is paramount. For this reason, EU law has introduced specific provisions to incentivize such operations during the demolition of buildings. According to the WFD (2008/98/EC), "Member States shall take measures to promote selective demolition in order to enable removal and safe handling of hazardous substances and facilitate reuse and high-quality recycling by selective removal of materials, and to ensure the establishment of sorting systems for CDW at least for wood, mineral fractions (concrete, bricks, tiles and ceramics, stones), metal, glass, plastic and plaster." Furthermore, in the revised WFD (2018/851), it is suggested that, by 31 December 2024, the European Commission should consider setting preparation-for-reuse and recycling targets for CDW and its material-specific fractions.

There have been a few EU member states that have set regulatory requirements for obligatory selective demolition, but sorting and separate collection of waste are still more common. For instance, the new "Recycled Construction Materials Ordinance" in Austria (Recycling-Baustoffverordnung, BGBl. II Nr. 181/2015) provides a good example of a progressive regulation that institutionalizes waste prevention and management practices that aim at higher efficiency in the construction and demolition sector.

2.4.3 Pre-demolition Audits

Another enabling activity, enhancing the potential of selective demolition and recovery of CDW, is the so-called "pre-demolition audit," which provides an inventory of buildings' materials before it is demolished (Akanbi et al. 2018). Traditionally, pre-demolition audits were focused on identifying and managing hazardous waste fractions and components through separate collection that protected the remaining waste fractions from contamination; however, auditing for reuse and recycling opportunities is expected in EU and national legislation (Nußholz et al. 2019), as in the example of the Austrian "Recycled Construction Materials Ordinance" (Recycling-Baustoffverordnung, BGBl. II Nr. 181/2015).

2.4.4 Economic Instruments

A common approach to divert waste from unsustainable disposal practices is the taxation of activities low in the waste hierarchy, mostly applied to disincentivize landfilling (e.g., landfill taxes). However, since the vast majority of CDW consists of inert mineral substances, it is common for this type of waste to be exempt from such taxes under the pretext that the waste will be used for landscaping, as structural elements of a landfill, or as energy recovery in incinerators. To ensure recycling and encourage higher value uses, Austria has implemented an alternative to the landfill tax, where a charge of 9.20 EUR is imposed for every tonne of CDW that is not recovered by the applied national standards (Altlastensa- nierungsgesetz (ALSAG) – law for Remediation of Contaminated Sites) (Danish Environmental Protection Agency 2017).

Another approach to taxation that can influence the efficient use of construction materials includes taxes and levies on the virgin sources of materials (EEA 2016). For instance, such a case is observed in France, where a tax of 0.2 EUR/tonne is imposed on extracted materials. In the UK, the "Aggregates levy" imposes a £2/ tonne fee on the extraction of virgin aggregates used in construction (Danish Environmental Protection Agency 2017).

2.4.5 Construction Product Standards

To support the production of building materials with secondary raw materials or the reuse of existing building components, building material standards can be used to provide technical specifications and certify the quality and safety of the "secondary" construction products. These standards can be obligatory (e.g., CE marking for original building products) or voluntary and developed either on the initiative of sectoral actors in collaboration with standardization authorities or mandated by a competent authority at EU or MS level (Tecchio et al. 2017).

The Construction Products Regulation (CPR) (Regulation (EU) no. 305/2011) defines a common technical "language" for performance requirements for construction products and harmonized European Norms (hENs) "provide the methods and the criteria for assessing the performance of the construction products in relation to their essential characteristics" (Regulation (EU) no. 305/2011). For products that fall out of harmonized standards (e.g., recovered building components), the CPR provides an alternative method (Condotta and Zatta 2021). Harmonized standards have been adapted for reused bricks, for example; the trading of reused bricks has become a growing market, where old bricks can be bought with a quality assurance on the same basis as a new brick. Issues with CPR and CE-labeling for reused building materials are discussed later in this chapter.

2.4.6 Environmental Product Declarations (EPDs)

In addition to technical requirements, environmental product declarations (EPDs) have proliferated in the sector. EPDs provide standard information about the environmental performance of construction products and materials, thus facilitating the tracking of the environmental performance in the value chain. EPDs have become increasingly influential in procurement decisions (Passer et al. 2015).

2.4.7 Building Codes

At the design and planning stage of construction, national building codes can promote the use of secondary materials or reused components. Building codes are mandatory for construction permits and ensure compliance with public health, safety, and material standards (Listokin and Hattis 2005). More recently European

Commission mandates, e.g., M/515, M/128, and M/130, have incorporated more standards pertaining to minimizing climate and other environmental impacts (Nußholz et al. 2019).

2.4.8 Building Certification and Standards

There are also voluntary building certification schemes, e.g., BREEAM, DGNB, HQE, and LEED, that have criteria for sustainable material use and sound management of CDW. Voluntary standards for the design, construction, and demolition of buildings provide guidance to the buildings sector for increasing resource efficiency. For instance, the Canadian CSA Group has produced a series of voluntary standards, such as "CSA S478:19 Durability in buildings" and "CSA Z783-12 Deconstruction of buildings and their related parts."

2.4.9 EU Circular Economy Tools

The new CE Action Plan (COM(2020) 98 final) reiterates the resolution of the 2015 CE Action Plan (COM(2015) 614 final) recognizing construction and demolition as a priority area and outlines relevant actions to be taken for the achievement of a circular economy. To address the challenges identified in the construction sector to increase resource efficiency and circularity, the European Commission has produced the guidance documents and tools to enable better management of CDW and building components (Table 2).

3 Challenges to Upscaling

There are many challenges to upscaling circular economy strategies in the building and construction sector, starting with assumptions made in the design of buildings. A relatively short lifecycle for buildings has become a norm in the building industry and underpins important assumptions in accounting. Marsh (2017) found that sustainability tools such as LCA modeling used in the Nordic countries often use short building lifespans of 50–60 years in assumptions, which meant the environmental advantages of a longer lifetime for buildings are not being fully considered and assessed.

For a long time, there has been a focus on increasing the energy efficiency of buildings, in the EU in accordance with the Energy Performance of Buildings Directive (Dir. 2010/31/EU) (EPBD) and the Energy Efficiency Directive (Dir. 2012/27/EU) (EED). The work on energy efficiency in buildings is essential, but the prioritization of energy efficiency and high energy performance of buildings has also been noted as de-prioritizing using building design and materials for deconstruction and reuse (Hossain et al. 2020). Thermal performance data of reused materials must be also available, to be able to carry through renovation processes with a high energy-efficiency standard and low carbon impact. Significant questions remain, related to potential trade-offs between energy efficiency strategies and circular strategies. For example, extending the lifetime of inefficient components and products in buildings is at odds if there are potential energy efficiency gains

Table 2 Tools for improving circularity in the construction sector (Wahlström et al. 2020)

Action	Details
EU Construction and Demolition Waste Management Protocol (EU Commission 2016)	Demolition, renovation, or construction projects need to cost-effectively reduce environmental and health impacts. The Protocol lists the following actions to improve CDW management and trust in the quality of recycled materials: (a) Improved waste identification, source separation, and collection (b) Improved waste logistics (c) Improved waste processing (d) Quality management (e) Appropriate policy and framework conditions
EU Waste Audit Guideline (EU Commission 2018)	The Guideline describes the waste audit process. The waste audit should produce an inventory of materials and components anticipated from (future) demolition, deconstruction, or refurbishment projects, and provide options for their management and recovery
Building sustainability performance – Level (s) (EU Commission 2019)	This is a voluntary reporting framework to improve the sustainability of buildings including indicators for reducing environmental impacts and for creating healthier and more comfortable spaces for occupants
Renovation Wave Strategy (EU Commission 2020)	This strategy adopts the principle of "lifecycle thinking and circularity" to make buildings "less carbon-intensive over their full life-cycle" EU Commission (2020). Renovation rates can be expected to increase as a result of the strategy, but it is important to include and optimize several environmental aspects within this initiative to reach targets not only for energy use, but also on circular economy and carbon impact and achieve sustainable buildings over time

through replacement and renovation rather than lifetime extension and reuse (Volland et al. 2020).

It is also not clear in all cases that following the waste hierarchy leads to optimal solutions. For example, recycling processes of the materials might require significant energy use or long transportation. Waste is often used as an energy source. A change toward a more circular building industry needs to be made with this taken into account. An example is the connection between waste and district heating, for example in Sweden. If reused building materials are a solution for a long-term sustainable building industry, then there needs to be consideration of how energy production that is now supplied by this waste will be replaced. It is not clear if some material is actually better used as an energy source for CHP plants than to reuse them in another construction project.

An important challenge is to gain knowledge regarding the capacity of used materials. Methods are needed on how to ensure characteristics such as strength, durability, density, and purity. These methods will vary depending on what material is analyzed. In addition, they need to be financially affordable to make the reused product competitive, compared to a new produced product. Another aspect is that the optimal lifetime of a material or component will vary, depending on what product. For instance, the energy performance of a component might be at such low level that the product is inappropriate to reuse, even though its functional lifetime is not yet reached. The test methods must also include the aspects of performance.

Traditionally, the real estate market is based on the price of land. When the market also includes the building materials on the real estate, many legal issues are raised. With a shift toward a circular building industry, the legal real estate framework is in many ways different and new to all involved, which therefore requires another perspective than the previous ones. The legal framework regarding the responsibility for a reused product is inexplicit and there are several aspects of these regulations that need to be considered in order to innovate them. For instance there are questions about the boundary between real estate and movable property and what happens in the transition from real estate to movable property and back to real estate. In addition, the question of financial security in connection with property acquisitions needs to be solved.

There is currently a lack of clear business cases for circular economy strategies in the face of cheap new virgin raw materials and established linear supply chains and design processes. In the municipal sector, there are barriers in the form of a shortage of skills, awareness, and resources. Several market and technical barriers pose challenges for the construction sector as well as a persistent short-term view of economics in general, and resistance to change (Gustafsson 2019).

A sustainable building industry is not only connected to energy, resources, carbon pollution, and waste. It is a large sector for employment and a sustainable building industry also means a good working environment throughout the full value chain. There is a risk of bad working conditions both on building sites and in the extraction of raw materials. It is necessary that the transformation toward a circular building industry does not result in trade-offs with social sustainability aspects.

3.1 Policy Challenges

Despite the extensive regulatory initiative observed in the last decade (see Table 1), there are still several policy challenges in increasing the circularity of the construction sector. A major challenge is to adapt the construction industry's comprehensive legal framework so that the regulations do not provide opposite instructions but instead work together to enable a movement toward a circular construction industry.

While there is recycling legislation for CDW, the targets do not incentivize high-quality recycling. In practice, the heaviest fractions of CDW are not easily recyclable to an equal or higher quality and most often are downcycled, fulfilling backfilling operations (Debacker and Manshoven 2016). In addition, product standards such as

CPR are designed based on products made from virgin material sources and do not favor the use of recovered building components (reuse). European regulations concerning CDW management and construction product requirements are not specific or clear on reclaimed building elements. While reuse is recognized as a resource-efficient and sustainable process by several EU tools such as protocols and guidelines (EC 2016, 2018), the main regulation concerning the standards for marketing construction products does not mention reuse (Regulation (EU) no. 305/2011). (Condotta and Zatta 2021).

Quality aspects and guarantees are of major importance within the building industry and is often mentioned as an obstacle to the transformation toward a circular building industry. Many building companies today demand compliance with standards and CE-labeling for all construction materials used in their projects. Since current regulations are based on a linear building process that only considers virgin building materials, using reused building materials is often a deviation from regulations. This deviation implies a risk for organizations involved in the building project that requires time, money, and expertise to manage. Even if alternative methods for reused products are provided, the time and costs required for this alternative certification make the process unattractive for many operators, since reclaimed building components would usually need to achieve end-of-waste status and receive a technical assessment from a competent body for individual products (in contrast to formalized products in a "traditional" production line) (Condotta and Zatta 2021). Another important aspect is the possibility to insure a reused product or insurance of buildings using reused building materials. It is important that the insurance companies are committed to the transformation and this is not a barrier.

Barriers in planning also need to be addressed. For example, in detailed development plans in current regulations, the use of the buildings is specified, often for a long period of time. This makes it very difficult to reuse the building for another purpose. Another issue related to detailed development plans is shared spaces. For example, sharing office space and using it for other activities is only possible if it is permitted in the detailed plans set by the local municipality.

There are also tensions and potential trade-offs between the different objectives of policies. For example, potentially reusable components and materials may contain hazardous materials (and then not meet current CE-labelling requirements, particularly in regards to chemicals), which then undermines its potential reuse. Because of the comprehensive regulations surrounding buildings and building materials, there is a danger that all the collected components and materials from careful demolitions will simply pile up and eventually be disposed of as waste anyways. The trade-offs between the impacts of eliminating certain chemicals in products versus the impacts of using virgin material need to be further considered in policy and guide the development of standards for reused and recycled materials. Energy performance and renovation policies may also prioritize energy efficiency aspects over circularity aspects, especially if the value of a building is determined by its energy performance – see EU Commission 2021.

4 Changes Needed

A paradigm shift is needed regarding the construction of buildings. Thinking and planning the full lifecycle of a building needs to happen from the start of the design process itself. Waste prevention must be the initial position, and eventual deviations from this closely motivated. There is a need to change assumptions in the industry and those underpinning tools like LCA to ensure the tools are considering longer lifetimes and a range of circular strategies are being considered. There is a need for new financial models, a new setup for purchasing real estates, and regulations regarding detailed development plans and demolition plans.

Reuse and conservation of existing buildings need to be prioritized over replacement and new buildings, but this is currently not the case and needs to change in the industry (Huuhka and Vestergaard 2019). While many existing policies have objectives for reuse, the mechanisms to promote reuse are weak and need to be strengthened (Rose and Stegemann 2019). There is still a strong preference and even incentives for the demolition of buildings over renovation or refurbishment. For instance, it has been noted in the UK that there are value-added taxes of 20% for refurbishment and renovation projects while new builds are exempt and these perverse tax incentives need to be questioned (Baker-Brown 2017). Demolition is often promoted for the removal of substandard housing; however, increasingly the logic of this practice has been questioned in terms of both environmental and social value (see, e.g., Power 2010; Merlino 2020).

Deconstruction is the final stage of a building's lifecycle and needs to be included and considered already at the design stage. There is a lack of knowledge regarding this step in the design of a building construction. More research is needed regarding load-bearing structures, fire-safety, acoustics, etc. to ensure a building with excellent performance during its lifetime but also includes a safe dismantling of the construction, where as much material can be reused as possible. Research on optimization is also needed to be able to meet relevant target parameters on sustainability. This optimization must handle many different parameters and aspects to avoid sub-optimization.

Condotta and Zatta (2021) argue that one of the most critical actions to be taken is to stop considering reusable elements as waste, enabling re-users to reduce unnecessary costs and certifications, as well as assessment time. The recycling process needs to be adapted to provide higher quality recycled materials, potentially adding new process steps for material separation. All deconstruction plans should include detailed descriptions of where the materials will be used next, and the local municipality should offer a platform for the registration of materials available.

Much of the data about stocks and flows of materials in the built environment is either still being developed or aggregated in such a way that it limits its usefulness for increasing circularity, particularly reuse (Rose and Stegemann 2019; Huuhka and Kolkwitz 2021). In collecting data about buildings, components, and materials, qualitative attributes are also necessary. For example, in their inventory of prefabricated concrete panels in Finnish housing, Huuhka et al. (2015) included data about the form and condition of panels that could be used in planning reuse.

Including more data about the form and condition of reusable components and material needs to become the norm for planning reuse (Rose and Stegemann 2019). Access to information about construction products and construction methods is also important for the demolition and recycling companies.

There is still a lack of legislation promoting circular construction in key areas, e.g., lack of circular requirements in procurement or extended producer responsibility requirements. There is also a need to harmonize schemes for accounting for material life cycle impacts. There are voluntary schemes for accounting for chemicals in construction products, most notably BASTA1, and such schemes can be applied in, e.g., procurement. National agencies also make use of pilot projects and technology procurement to achieve certain objectives, such as the development of new techniques and a more cost-effective renovation process for more energy-efficient housing.

Many current regulations are not well adapted to be considered and applied to reused materials. To reach a high level of reused materials in everyday building projects, standards equally suitable for both virgin and reused materials must be available. Revised regulations are needed to ensure the quality and content of a reused material. REACH must be adapted to include reused materials and an alternative to the CE-labeling is needed to get a broad scale use of reused materials in the building industry, where the quality assurance is made equally, based on a standardized system. It is however still unclear how regulations should be applied to reused materials. Since the regulations are set on a European level, international collaborations are needed between member states. Now, the way reused material sources are classified and dealt with, even within the context of the harmonized standards, still differs significantly between countries. Circular trading of materials needs to be developed to ensure safe trading with comparable ease of linear systems. The existing material trading places generally only trade goods, and do not take responsibility regarding quality or durability, with no equivalent of CE-marketing offered.

5 Outlook

Wahlström et al. (2020) presented an outlook of a future construction sector and the conditions required for achieving circularity (Table 3) that includes many of the changes needed to address challenges and realize the full potential of circular strategies discussed in this chapter.

There are important trends in construction that are already changing and enabling more circularity for the building and construction sector. Some shifts in thinking of actors within the building industry are evident. For example, the Architect's Journal has launched a RetroFirst campaign to prioritize refurbishment over demolition and new building with one of its primary demands is reforming VAT and building codes (Wainwright 2020). In particular, the development of digital tools and other policy developments have significant potential for further upscaling circularity in the near future.

Table 3 Examples of circular economy actions for better construction and demolition management (Wahlström et al. 2020)

Lifecycle	Examples of circular economy action	Conditions (examples)
Design phase	Design for reuse, repurposing, and recycling	Less complex products Standards and increased standardization of components and materials.
Material production phase	Material choices, and the use of a high content of recyclables	Closing the loop (may require new technologies) Improved quality of separated waste fractions Material documentation
Construction phase	Lifetime optimization for more circular products	Digitalization, BIM, traceability, materials passports
Use phase	Maintenance for extension of lifetime	Planned maintenance, use of sensors, etc. for optimizing maintenance or renovation
End-of-life phase	Separation of different materials with a low content of impurities, less complexity, and technology development	Improved recovery of materials improved collection and separation for clean, pure fractions Improved traceability and documentation

The increasing use of BIM brings with it potential for better data available that could be coupled with building passports to give better information about all lifecycle stages of buildings (Volk et al. 2014). Building passports are single repositories of compiled life cycle building information about a building and its site, including technical, environmental, financial, and social data. They can provide a wide range of stakeholders along the value chain and life cycle of the building with relevant information to ensure more circular designs and better management of use, reuse, and end-of-life strategies for buildings. They can also improve transparency and trust, and improve policy decisions (Global Alliance for Buildings and Construction and United Nations Environment Programme 2021).

Building passports and better building information can be used by trading platforms to connect actors in deconstruction and construction, but also designers and architects to see what materials might be available within the timing of the projects. The development of complex, extensive, and connected information systems is ambitious but necessary to enable higher quality and quantity of material reuse in the building sector (Rose and Stegemann 2019).

The voluntary environmental classification systems BREEAM and LEED continue to expand in scope and have started to address issues like embedded energy by requiring information about material choice. For LEED, credits are possible within "Materials and Resources; Sourcing of Raw Materials." Both reused materials and materials with recycled content are awarded. Reuse includes salvaged, refurbished, or reused products.

There is an ongoing revision for CPR within the European regulatory framework on building components. This work is closely connected to the Sustainable Products

Initiative, and the results of both these revisions will be presented together in 2022. The EU Industrial Strategy, including possible transition pathways for a more resilient, green, and digital construction ecosystem, is also under revision with its results presented later in 2022. This strategy highlights the need to accelerate EU industry's green and digital transitions.

One of six environmental objectives within the new European Taxonomy Regulation (EU Commission 2021) for sustainable investment is the transition to a circular economy. By using this policy and adding value to a real estate by including circular economy aspects, it is very likely that the transition toward a circular building industry will increase in speed. Another good opportunity to increase circular economy aspects within the European building sector is the Recovery and Resilience Facility (RRF), launched in 2021 by the European Union to "mitigate the economic and social impact of the coronavirus pandemic and make European economies and societies more sustainable, resilient and better prepared for the challenges and opportunities of the green and digital transitions." The RRF finances investments from February 2020 until 31 December 2026. To receive financing, Member States submit recovery and resilience plans to the European Commission. No measure included in a Member State's Recovery and Resilience Plan (RRP) should undermine any of the six environmental objectives within the Taxonomy Regulation, and the transition to a circular economy is one of these objectives. Member States need to provide a Do No Significant Harm (DNSH) assessment for each reform and each investment. When all reforms and investments must be made pursuant to causing no harm to possibilities for a circular economy, it is a great opportunity for the transformation to take place at an accelerated rate.

Policies on multiple levels will continue to push for circularity in production and consumption systems. The societal goal for a more circular economy and a special focus on the building sector to achieve sustainable development goal 12 will continue to push the building sector in a more circular direction.

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