Chapter 1
Circular Economy Best Practices in the Built Environment

Genesis Camila Cervantes Puma, Adriana Salles, Janez Turk, Vlatka Rajčić, Almudena Muñoz Puche, Kinga Korniejenko, Themistoklis Tsalkatidis, Vanessa Tavares, Rocio Pineda Martos, Tatiana Ruchinskaya, and Luís Bragança

Abstract This document serves as the opening chapter of a book that addresses the critical issue of resource depletion in the built environment, illustrating the unsustainable trends in current construction and demolition practices that extensively rely on new raw materials. It highlights the significant impact of the building sector on

G. C. Cervantes Puma (✉) · A. Salles · L. Bragança
ISISE, ARISE, Department of Civil Engineering, University of Minho, 4804-533 Guimarães, Portugal
e-mail: cami_cervantes@hotmail.com

A. Salles
e-mail: adfsalles@gmail.com

J. Turk
Slovenian National Building and Civil Engineering Institute, Ljubljana, Slovenia

V. Rajčić
Faculty of Civil Engineering, University of Zagreb, Zagreb, Croatia

A. Muñoz Puche
R&D Project Manager, Technological Center of Furniture and Wood of the Region of Murcia, Calle Perales s/n 30510, Yecla (Murcia), España
e-mail: a.munoz@cetem.es

K. Korniejenko
Cracow University of Technology, Kraków, Poland

T. Tsalkatidis
Norwegian University of Life Sciences, Ås, Norway

V. Tavares
BUILT CoLAB, Porto, Portugal

R. P. Martos
School of Agricultural Engineering ETSIA, University of Seville, Sevilla, España

T. Ruchinskaya
TVR Design Consultancy, 6 Green Street, Willingham, Cambridgeshire CB24 5JA, UK
e-mail: tvr281@hotmail.co.uk

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global resource consumption, energy utilization, and waste generation, with alarming statistics such as buildings accounting for 40% of the world's extracted materials and a significant source of waste and greenhouse gas emissions. Advocating for a transformative shift towards a circular economy in the built environment, the text emphasizes sustainable and regenerative economic practices that minimize waste and maximize resource efficiency. This approach necessitates the redesign of systems to ensure the durability, reparability, and recyclability of construction materials, thereby promoting a model where waste is systematically eliminated and materials are continually repurposed. The document also discusses the 10R strategy, which centres on minimizing waste and enhancing resource efficiency, and explores various circular practices within the construction sector. It includes examples from case studies and best practices to demonstrate the viability and advantages of adopting circular economy principles. The challenges and success factors in implementing such practices are thoroughly examined, emphasizing the urgent need for increased awareness, supportive policies, and robust stakeholder collaboration to foster a more sustainable and resource-efficient built environment. The first chapter sets the stage for a detailed exploration of these themes throughout the book's subsequent sections.

Keywords Circular economy · Built environment · Sustainable construction · Resource efficiency

1.1 Introduction

Our current society, driven by a culture of disposability, is depleting the Earth's valuable and limited resources at an alarming pace [1]. The built environment is a prime example of this phenomenon, where buildings are frequently stripped down and demolished, only to be replaced by new structures constructed from new raw materials. Unfortunately, little to no regard is given to the significant environmental and social consequences associated with the extraction and processing of construction materials. Equally concerning is the lack of consideration for the eventual fate of our buildings [2].

The built environment is a major contributor to resource consumption, accounting approximately 40% of the world's extracted materials [3]. Buildings and construction account for the consumption of approximately 40% of the natural resources worldwide, 70% of electrical power and 12% of potable water. Moreover, buildings and construction were responsible for consuming 35% of final energy and generating 38% of emissions in 2019. Buildings might have a crucial role in achieving carbon neutrality, circularity, and sustainability of the built environment through the renovation of building stock. For example, 75% of building stock existing in European Union is non-energy efficient and is not in compliance with the current legislation as 90% of building stock was built before 1990 [3].

The demolition and constructions activities associated with it generate the largest waste stream in many countries. For instance, in the European Union (EU27), construction and demolition activities generated 37.5% of the waste produced in all economic activities in 2020, that together with the activities of mining and quarry (mostly intended for the construction industry) totalised 60.9% of waste produced. The extraction of raw materials necessary for construction is becoming increasingly challenging, leading to heightened environmental strain as delicate ecosystems are exploited. In the near future, it is expected that extraction and use of raw materials will be exacerbated considering the actual consumption of these raw materials for construction and urban areas (urban areas currently consumes 75% of existing natural resources and generates 50% of solid waste and 60% of greenhouse emissions on a global scale) and the projected increase of population living in urban areas (68.4% of the projected 9.7 billion inhabitants in 2050).

Additionally, geopolitical factors contribute to price volatility and disruptions in the supply of essential raw materials. Adding to the complexity, the demand for resources is projected to escalate as the global middle class is expected to double in size by 2030. For instance, global steel demand alone is forecasted to surge by 50% by 2025 [4]. These trends highlight the urgent need for sustainable approaches in the built environment to address resource scarcity and minimise environmental impact.

Unfortunately, building design frequently prioritises the immediate needs of current users without considering the future implications. A building is often composed of intricate components, incorporating a wide array of materials and polymers that are intricately fused together. This complex composition poses a significant challenge for future retrieval or separation of these materials [5].

A more forward-looking approach that considers long-term sustainability and resource availability is essential to ensure that valuable resources are effectively conserved and available for the benefit of future communities [5]. To this end, under the different headings, an overview of the basic concepts of circular economy in the built environment is presented, such as circular materials, design, modularity, reuse of existing building etc. The report will then continue with different examples of case studies and best practices for each of these concepts and, finally, a few lessons will be derived, key challenges and success factors from the implementation of the circular economy in the built environment.

1.2 Circular Economy

The circular economy is a ground-breaking economic model that seeks to transform the traditional linear model of "take, make, dispose" into a more sustainable and regenerative system. It emphasises the principles of elimination of waste and pollution, optimization of material use, and regeneration of natural systems to promote the creation of a circular flow of goods in the economy. This involves designing products to be durable, repairable, and recyclable, thus extending their life, see Fig. 1.1.

At the heart of the circular economy lies the idea of valuing products and materials as resources that merit preservation and creating strategies that promote the reuse and regeneration of these resources. This approach can help reduce the depletion of

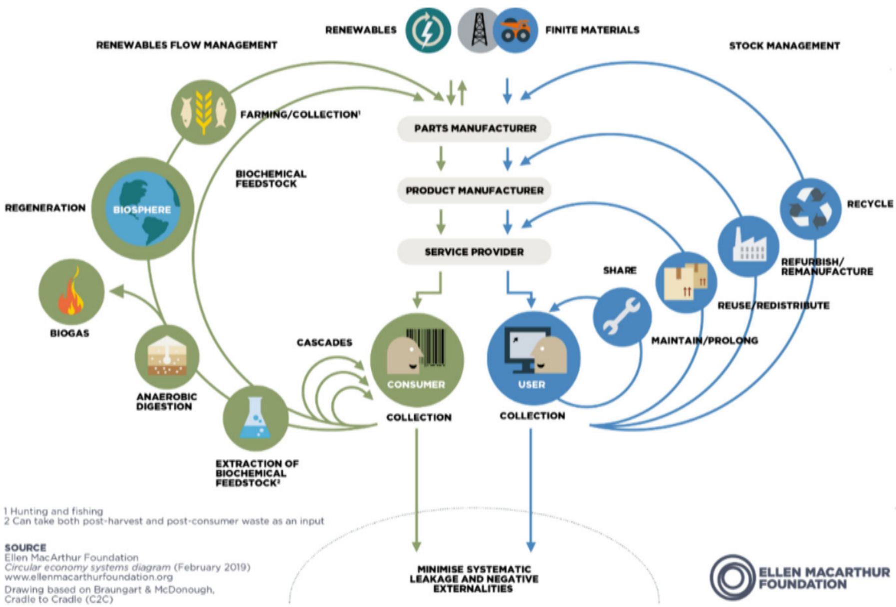

Fig. 1.1 The butterfly diagram: visualising the circular economy [6]

natural resources and minimise the environmental impact of waste generation and disposal, leading to a more sustainable model of economic development [7].

Moreover, the circular economy recognises the need to achieve sustainable development through a triple-bottom-line approach to economic performance, i.e., taking into consideration environmental, social, and economic factors simultaneously. This approach recognises the interconnectedness of these three factors and emphasises the importance of ecological stewardship, social development, and economic growth in achieving sustainable development [8].

The circular economy can have several benefits for businesses and societies that adopt its principles. First, it can lead to increased resource efficiency, reduced waste generation, and the development of innovative business models that promote economic growth. Second, it can contribute to the preservation of ecosystems and the mitigation of climate change, making it a desirable approach for professionals seeking to promote sustainability and resource efficiency in business practices. Third, circular business models can create opportunities for job creation and contribute to social development, particularly in underserved communities that have been disproportionately affected by a non-circular economy [8].

Europe has emerged as a global leader in promoting and implementing the circular economy concept. The EU has adopted several policies and initiatives aimed at supporting its implementation, including the Circular Economy Action Plan [9] and the Circular Economy Package [9], which promote sustainable consumption, production patterns, and waste reduction. EU member states have implemented waste management and recycling targets to minimise landfilling and increase material recovery, and Extended Producer Responsibility schemes hold manufacturers accountable for the end-of-life management of their products, promoting product design for durability, reparability, and recyclability [10].

In conclusion, the circular economy represents a fundamental shift towards sustainability and regenerative economic systems that align with social and environmental goals. By prioritizing the reduction of waste and pollution, optimizing material use, and regenerating natural systems, this model presents an alternative to the traditional linear model, leading to a more sustainable and regenerative system. It promotes an economic growth that considers environmental, social, and economic factors simultaneously, recognizing their interconnection [8]. The circular economy has several benefits for businesses and societies, including job creation and social development, promoting sustainability and resource efficiency in business practices, and ecosystem preservation and climate change mitigation. Europe has emerged as a leader in promoting and implementing this concept, with policies and initiatives aimed at supporting its implementation [11]. The circular economy represents a fundamental shift towards sustainability, which offers a promising future for a more sustainable and inclusive economy.

Principles

The principles of the circular economy are centred around designing out waste by creating a system in which there is no waste. To achieve this goal, products are designed to last, using high-quality materials, and optimised for a cycle of disassembly and reuse that facilitates their transformation and renewal.

The circular economy distinguishes between technical and biological cycles, with consumption only occurring in the biological cycles. Biologically based materials such as food, linen, or cork are designed to feed back into the system through anaerobic digestion and composting to regenerate living systems such as soil and oceans, providing renewable resources for the economy. In contrast, technical cycles focus on recovering and restoring products, components, and materials through strategies such as reuse, repair, remanufacturing, or recycling [12].

The goal of the circular economy is to optimise resource yields by always achieving the highest possible utility of products, components, and materials in use in both technical and biological cycles [13]. This means that products are designed to be used for as long as possible before being disassembled and reused or recycled. By doing so, the circular economy aims to reduce waste and minimise the use of virgin materials.

The final principle of the circular economy seeks to use renewable energies to fuel the system, reducing dependence on finite resources and increasing systems' resilience. This principle emphasises the need to design out negative externalities and develop effective systems that promote sustainability [11]. In review, the circular economy is a production and consumption model that prioritises minimizing waste, reducing resource consumption, and promoting sustainable use of natural resources. It aims to create a sustainable economic system that can support the needs of both current and future generations while minimizing its environmental impact [13].

By adopting design principles that focus on reducing waste and pollution, extending the life of products and materials, regenerating natural systems, optimizing resource yields, using renewable energies, reducing dependence on finite resources, increasing systems' resilience, designing out negative externalities, and developing effective systems that promote sustainability, it can create a sustainable economic system that meets the needs of current and future generations [11].

10R Strategy

The 10R strategy is a pivotal element of the circular economy, providing several sustainability advantages (see Fig. 1.2). This approach involves designing out waste by implementing a waste-free system which concentrates on high-quality products and materials that are optimised for disassembly and utilization [14]. The technique differentiates between technical and biological cycles, with consumption only taking place in the biological cycle [15]. Biologically based items are designed to regenerate living systems such as soil and oceans by feeding back into the system through anaerobic digestion and composting. In contrast, components and materials are recovered and restored through strategies like reuse, repair, remanufacturing, or recycling in the technical cycles [14].

The goal is to optimise resource yields by obtaining the highest possible utility of products, components, and materials in both technical and biological cycles [16]. Products are designed to be of highest use for a long time before being disassembled and reused or recycled, minimizing waste, and decreasing the reliance on virgin materials [14]. As a result, businesses can achieve triple bottom line sustainability benefits that include economic, social, and environmental advantages [16].

By following the 10R strategy, businesses can reduce their environmental impact, create new opportunities for growth and cost savings, promote the circular economy, and drive innovation [14]. By adopting a sustainable future, businesses can play their role in lessening reliance on virgin materials and resources, contributing positively towards a sustainable future.

The 10R strategy offers numerous sustainability benefits, including reducing waste and improving efficiency throughout the product life cycle, promoting the circular economy, and driving innovation [15]. By adopting the 10R strategy, businesses can reduce their environmental impact and boost their bottom line by creating new opportunities for growth and cost savings.

For example, by reducing the number of materials used in manufacturing and packaging, businesses can save on costs associated with raw materials, transportation, and disposal. Furthermore, by adopting a circular economy approach, businesses can reduce their reliance on virgin materials and resources, which can help to conserve natural resources, reduce greenhouse gas emissions, and mitigate climate change [15].

Overall, adopting the 10R strategy can help businesses to achieve triple bottom line sustainability benefits, which include economic, social, and environmental benefits. By reducing waste and improving efficiency throughout the product life cycle, businesses can reduce their environmental impact while also creating new opportunities for growth and cost savings [16]. By promoting the circular economy and

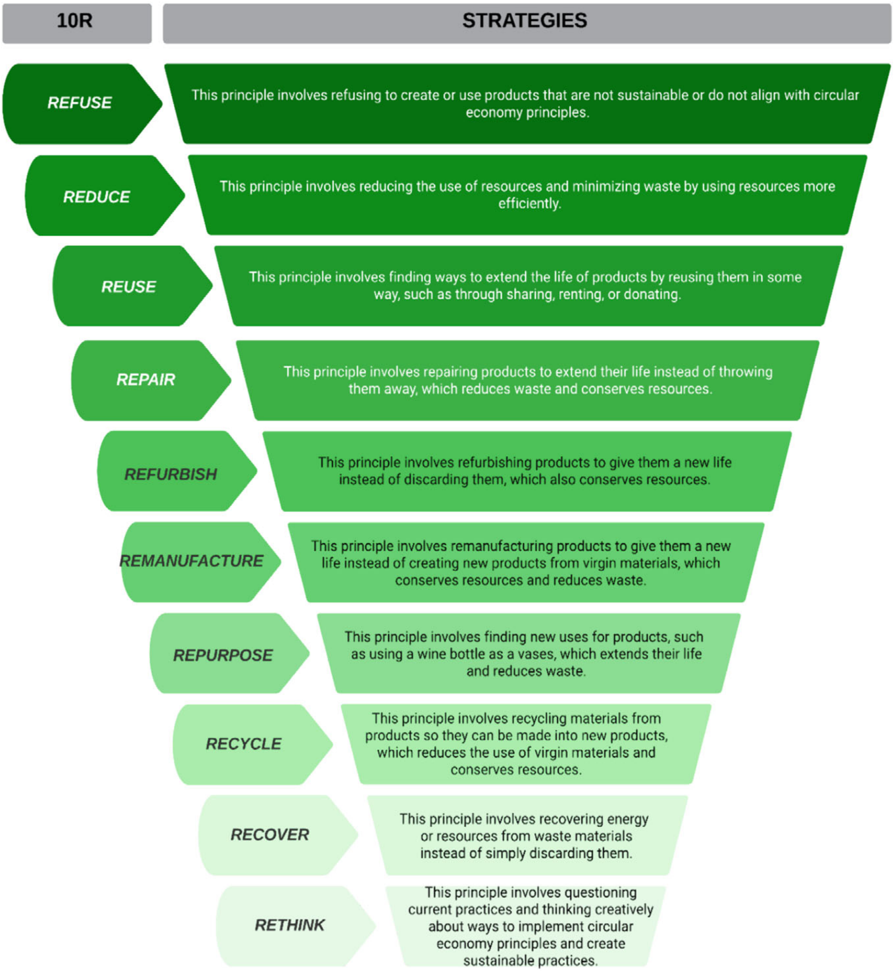

Fig. 1.2 10R strategy [16]

driving innovation, businesses can further reduce their reliance on virgin materials and resources while also contributing to a more sustainable future.

Benefits of Circular Economy

The circular economy offers numerous benefits that make it an attractive solution for promoting sustainability and reducing waste. These benefits (see Fig. 1.3) include environmental sustainability, economic opportunities, and social benefits [8]. By adopting circular practices, stakeholders can minimise the environmental impact of production and consumption, stimulate innovation and economic growth, create job opportunities, improve resource access and affordability, and enhance community resilience.

Fig. 1.3 Benefits of circular economy

One of the significant environmental benefits of implementing circular economy principles is that it can lead to a reduction in greenhouse gas emissions [5]. By promoting the reuse of existing products and materials, the circular economy can curtail the need for extracting natural resources, reducing the associated carbon footprint [8]. Additionally, by minimizing the use of virgin materials, the circular economy can help conserve natural resources and protect vital ecosystems such as soil, air, and water bodies. Moreover, circular practices and processes can lead to significant energy savings by reducing the need for resource extraction, manufacturing, and transportation of new products [8].

Another environmental benefit of the circular economy is that it can help to limit waste generation and reduce pollution. Circular economy practices such as recycling and remanufacturing can divert waste from landfills and incineration, thus promoting resource efficiency [17]. This, in turn, can help protect ecosystems, limit biodiversity loss, reduce landscape and habitat disruption, and contribute to the global effort to combat climate change.

By adopting these principles, the circular economy can create a sustainable economic system that meets the needs of current and future generations while minimizing its environmental impact [8].

1.3 Circular Economy in the Built Environment

The circular economy is an industrial economy that aims to restore materials and resources, relies on renewable energy, reduces toxic chemical use, and eliminates waste through careful design. It presents a tremendous opportunity to capture more value in the built environment. To tackle the complex nature of the built environment, the Ellen MacArthur Foundation worked with Arup to develop a roadmap towards a circular economy for building construction [18]. Courses, research frameworks, and reports, such as TU Delft's MOOC: Circular Economy for a Sustainable Built Environment, Circular Economy for the Built Environment: A Research Framework, and WorldGBC's Circular Built Environment Playbook, respectively, are available. The built environment industry has a crucial role to play (see Fig. 1.4) in transitioning towards a sustainable, circular economy.

Recovery and reuse of salvaged building materials and products from existing structures

Recovery and Reuse of Salvaged Building Materials in the Construction Industry

The recovery and reuse of salvaged building materials and products from existing structures is an essential practice in the context of circular material usage in the construction industry. Instead of demolishing buildings and sending the debris to landfills, salvaging materials by disassembly allows for their reuse in new construction projects, reducing waste and conserving resources [19].

Key Aspects of Recovery and Reuse of Salvaged Building Materials

Salvage operations involve carefully deconstructing or dismantling existing buildings to recover reusable materials, requiring skilled labour, proper tools, and techniques for safe removal and preservation. Materials are then identified, sorted, and assessed for usability and potential applications, including evaluating condition, quality, and

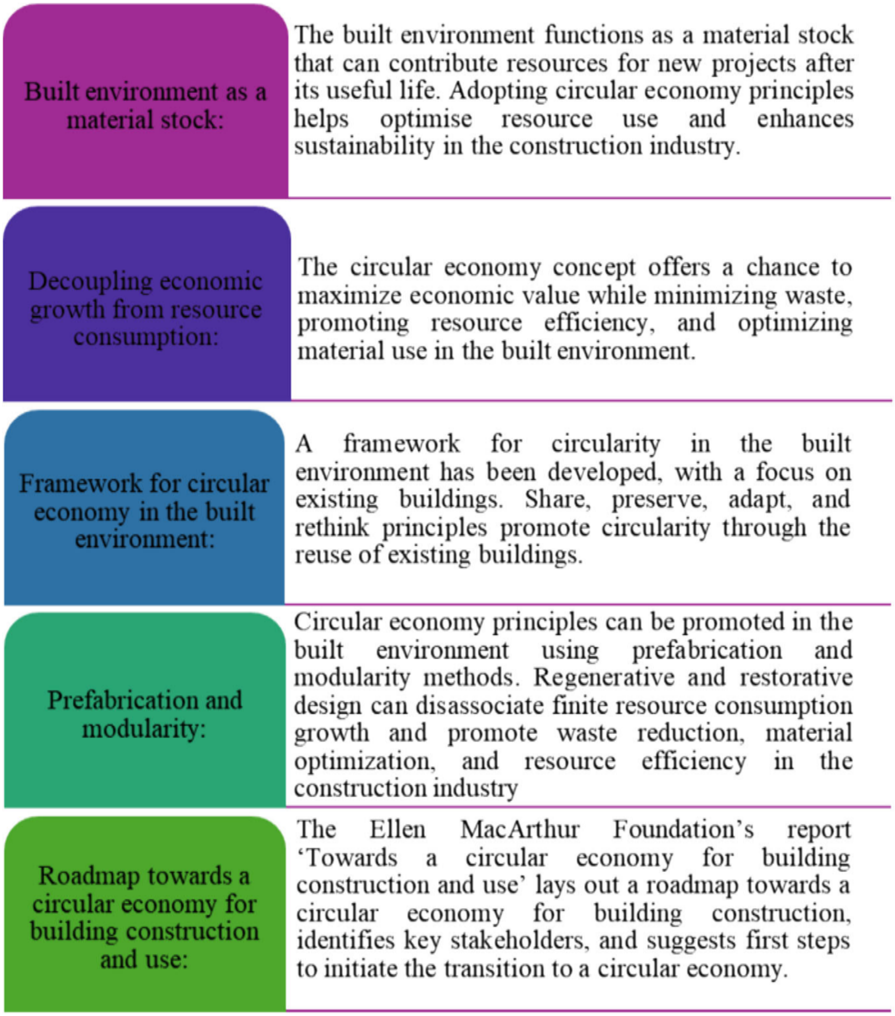

Fig. 1.4 Circular economy in built environment

compatibility [7]. Proper preservation and storage are necessary to maintain their quality, involving cleaning, repairing, treating, or storing materials appropriately. Salvaged materials should be assessed and tested to meet safety and quality standards, evaluating structural integrity, durability, and performance. Establishing an inventory and cataloguing system streamlines the reuse process, facilitating integration into new construction projects [19]. Designers and architects must consider characteristics, limitations, and aesthetics when incorporating salvaged materials while ensuring structural integrity and meeting regulatory requirements. Building networks and partnerships among stakeholders enhance reuse, allowing for exchange of information, expertise, and creation of marketplaces. By adopting these principles, the construction industry significantly contributes to sustainable practices by reducing waste, conserving resources, and promoting circular material usage [20]. See more information in Chap. 5, 'Recovery and Reuse of Salvaged Building Materials and Products from Existing Structures'.

Design for circularity

Design for circularity is a deliberate and systemic design approach that incorporates the fundamental principles of the circular economy. This approach is centred on minimizing waste, maximizing resource efficiency and promoting the reuse, recycling and regeneration of materials [21]. To achieve these objectives, design for circularity involves considering the entire life cycle of a product, from the sourcing of materials and the manufacturing process to the disposal of waste, with an emphasis on creating sustainable products and systems in a regenerative manner [21].

Key elements of design for circularity include the creation of products that are durable, easily repairable, and designed for disassembly, allowing for the recovery and repurposing of materials in a closed-loop system. Designers achieve this by adopting a range of techniques, including the use of recycled or renewable materials, building modularity and adaptability into designs, implementing product-service systems, and exploring opportunities for remanufacturing or refurbishment [21].

Material Selection and Management

The European Union (EU) emphasises the importance of applying circular economy (CE) principles across all economic sectors, including the construction sector. The criteria for selecting circular materials in the construction sector include:

1. Water and energy conservation: Circular materials should contribute to reducing water and energy consumption in the construction process.
2. Waste prevention: Circular materials should help minimise waste generation during construction and demolition activities.
3. Material recycling: Circular materials should be recyclable, allowing for their reuse in future construction projects.
4. Promotion of reuse and repair: Circular materials should be designed to facilitate reuse and repair, extending their useful life and reducing the need for new materials.
5. Utilisation of secondary raw materials: Circular materials should incorporate secondary raw materials derived from recycling or recovery processes.

By selecting materials that meet these criteria, the construction sector can contribute to the transition towards a less resource-intensive economy and promote circularity [12].

In the context of circularity, the European Union (EU) recognises the importance of critical raw materials, which are economically significant, sensitive to supply interruption, and have a significant environmental impact during extraction [22]. The EU aims to incorporate these materials into reduction, reuse, and recycling practices while seeking diversified and undistorted access to global raw materials markets and reducing external dependence and associated environmental pressures [23].

To achieve a less resource-intensive economy, it is recommended to prioritise the adoption of circular economy principles from the beginning of the production process. This includes designing production systems that efficiently use materials and enable recycling and reconversion of waste [12]. By incorporating circularity principles into the production process, economic models can be transformed, and the transition towards a less resource-intensive economy can be facilitated.

Selecting circular materials involves considering water and energy conservation, waste prevention, material recycling, promotion of reuse and repair, and utilisation of secondary raw materials [23]. The EU also emphasises the importance of incorporating critical raw materials into reduction, reuse, and recycling practices. Material efficiency, recycling techniques, waste prevention, and lifecycle assessment are key aspects of achieving circularity in material management and production systems [12].

Material recovery involves retrieving and reusing valuable materials from construction and demolition waste (CDW) [24]. This process includes activities such as deconstruction, which carefully disassembles structures to preserve valuable components [25]. Recovered materials can include lumber, cross-laminated timber, bricks, and other items that can be repurposed in future construction projects. The goal of material recovery is to reduce waste generation, conserve resources, and minimise the environmental impact associated with extracting new raw materials [25].

Recycling is an end-of-use strategy that involves reprocessing materials to be used in another product, thereby avoiding waste and the extraction of raw materials. In the construction sector, recycling often involves converting CDW into reusable materials, such as recycled aggregates, concrete, mortars, plastics, and gypsum Recycling CDW and other waste materials can contribute to resource conservation, waste reduction, and the promotion of sustainable material use [24]. More information is presented in Chap. 7 'Circular Material Usage Strategies/Principles'.

Modularity/prefabrication

Modularity and prefabrication bear immense significance in furthering the Circular Economy within the built environment. The integration of Circular Economy principles into modular construction allows for the development of a strategic framework that takes into consideration the entire life cycle of construction, ranging from design and production to use and end-of-life considerations [26]. The synergy of modularity and prefabrication with restorative and regenerative design can effectively overcome the trend of resource consumption growth, promoting the reuse of building components and aligning with the principle of decoupling economic growth from resource consumption. While the existing literature on the link between modularity and the Circular Economy remains limited, evidence suggests that these concepts augment resource efficiency, mitigate waste, and optimise material use, leading to a sustainable and Circular construction sector [26].

The benefits of integrating modularity and prefabrication into construction are manifold and significant for the Circular Economy in the built environment. Offsite manufacturing and assembly of building components have the potential to reduce material waste, maximise the utilisation of building materials and curtail transportation-related carbon emissions compared to traditional construction techniques [26]. Furthermore, prefabrication of building components offsite simplifies construction at the job site, expediting the construction timeline and minimizing the presence of workers on-site. Controlled factory environments enhance quality and consistency, leading to better-functioning and more durable buildings. Offsite construction can also improve job site safety by reducing hazardous conditions and minimizing work performed at high elevations [27]. Overall, modularity and prefabrication play an integral role in delivering higher quality, more durable structures while promoting environmental benefits and resource efficiency within the sector [27].

Prefabrication and modular construction offer several benefits for the Circular Economy within the built environment, some of which include shorter project durations, cost savings, enhanced site protection, superior product quality, reduced waste, and a closed-loop supply chain. Prefabrication and modular construction allow for faster and more precise manufacturing, leading to shorter project timelines, reduced construction costs, and economic sustainability [27]. Additionally, they minimise the impact of construction on the environment and surrounding communities, enhancing site protection while also improving product quality and promoting resource efficiency through optimised material use and waste reduction [26]. The closed-loop supply chain resulting from these practices further decreases the demand for virgin materials, as components are reused and recycled. Overall, the integration of prefabrication and modular construction techniques into Circular Economy principles offers numerous benefits and is crucial to advancing sustainability in the built environment (see more information in Chap. 8, 'Modularity/Prefabrication').

Reversible and transformable buildings

In a building context, the term "reversible" describes the process of transforming or dismantling a building's systems, products, and materials without incurring damages. A reversible building can, therefore, be dismantled, and its components can be reused, repurposed, or recycled. Similarly, reversible products can be designed and manufactured to enable the easy disassembly and reuse or recycling of their components. Reversible design is a fundamental principle of the circular economy, which seeks to keep resources in use for extended periods and eliminate waste [28].

Reversible building represents a strategic approach to architecture and construction aimed at creating buildings with reusable, repurposable, or recyclable materials, enabling them to be disassembled without causing damage [29]. This philosophy emphasises resource productivity and supports the ability of a building's components to revert to an earlier state, making the space easily adaptable to changing user needs [29]. Reversible design considers the technical and spatial dimensions, enabling efficient refurbishments and the disassembly, reuse, and/or recycling of the building's components [29].

Reversible products are of paramount importance to the circular economy, as they allow for the deconstruction and reuse of components, reducing waste and carbon emissions. "Reversible building" represents the backbone of circular building and the circular economy, involving the design of buildings and products that are easily disassembled and reused [29].

Reversibility and durability are potential indicators of circular economy design, highlighting the importance of designing easily disassembled, recyclable, or repurposable products, promoting sustainability in the industry [30]. Reverse logistics, which refers to the collection, repair, refurbishment, and recycling of products at the end of their useful life, is a crucial aspect of the circular economy. Manufacturers can use circular business models, whereby they maintain ownership of the product and are responsible for its upkeep throughout its life cycle, regardless of who possesses it [30].

The importance of reversible design is gradually becoming prevalent in calls for projects as reversible design allows products to be reconfigured, adapted, and repurposed to promote circularity in the production industry [30]. Overall, reversible products are instrumental to the circular economy, enabling the reuse and repurposing of materials and promoting sustainability in the production industry while reducing waste and carbon emissions (see more information in Chap. 10 ‘Reversible and Transformable Buildings’).

1.4 Case Studies and Best Practice Examples

The construction industry has long been recognised as a significant contributor to natural resource depletion and environmental pollution [31]. As a result, designers and manufacturers are increasingly focusing on sustainability and circularity in their operations to minimise waste and promote resource efficiency. This requires the adoption of various design concepts, including circular materials, modularity/prefabrication, design for circularity, and reversible building/products. However, to effectively implement these design concepts, it is essential to establish and follow best practices [31]. Best practices provide a consistent framework for achieving successful outcomes, optimizing performance, and ensuring regulatory compliance, among other benefits. In this article, we delve into the importance of best practices in achieving sustainable and circular design, highlighting their benefits and their critical role in successful implementation. Table 1.1 outlines the case studies in the next chapters.

Table 1.1 Case studies in the next chapters

Chapter N°	Case studies
Chapter 2 'Recovery and Reuse of Salvaged Building Materials and Products from Existing Structures'	1. Project ReCreate 2. Temporary market hall
Chapter 7 'Circular Material Usage Strategies/ Principles'	1. Gonsi Sócrates bio-building 2. Urban Mining and Recycling (UMAR) experimental unit 3. Open-spaced apartment 4. Escuela Politécnica superior
Chapter 4 'Modularity/Prefabrication'	1. Vertical timber extensions on existing building 2. FrameUp—optimisation of frames for effective assembling 3. SUPRIM case study
Chapter 5 'Reversible and Transformable Buildings'	1. People's Pavilion 2. Brasserie 2050 3. Triodos Bank 4. Koodaaram Kochi-Muziris Pavilion 5. Stadium 974

1.5 Challenges Faced in Implementing Circular Economy Practices in the Built Environment

The construction industry encounters economic challenges in adopting circular economy practices. A major roadblock is the insufficient level of awareness and knowledge of circular economy principles and practices among industry stakeholders. Additionally, there is an absence of incentives to design and construct buildings and products that can be easily disassembled and repurposed at the end of their operational life. These barriers pose significant obstacles to the adoption of circular design in the construction industry [32]. The implementation of circular economy practices in the built environment can also be impeded by technical obstacles. These challenges include a lack of standardization, complicated building systems, and the difficulty of disassembling and reusing materials. These technical barriers can pose significant difficulties for designers and constructors seeking to adopt circular economy practices in the built environment [33].

The implementation of circular economy practices in the construction industry can be impeded by several economic challenges. One such challenge is the limited research and application of circular economy concepts, which results in a lack of understanding of its full potential. Furthermore, the absence of a circular economy culture among stakeholders and resistance to change hinder the adoption of circular practices. Stakeholders may perceive implementation of such practices as costly due to insufficient regulatory frameworks and limited awareness of the benefits of circular practices [34]. Addressing these challenges involves collaborative efforts between stakeholders and government support, including the creation of new business models and metrics, adoption of innovative technologies, and establishment of economic incentives for circular products. Standardised metrics and increased demand for circular products are also important in overcoming economic barriers [35]. The design of buildings and products for disassembly and reuse at the end of their lifecycle is vital, but stakeholders may lack awareness and knowledge of circular economy principles and practices. In summary, there is a need for stakeholder collaboration, government support, and novel approaches to overcome economic obstacles and make the implementation of circular economy practices a reality in the construction industry [35].

The implementation of circular economy principles throughout the supply chain necessitates a clear economic justification, reinforced by metrics, tools, and guidance [36]. Technical barriers, such as absence of standardization, building system complexity, and the intricacies of disassembly and reutilisation of materials, pose significant challenges to the adoption of circular practices in the built environment. Moreover, a dearth of research and development in the circular economy concept limits comprehension of its vast potential within the construction industry [34].

Resistance to change alongside the lack of a circular economy culture among stakeholders presents another major obstacle to the circular economy's adoption. These impediments relate to stakeholders perceiving the high costs of implementing circular practices, inadequate regulatory frameworks, and insufficient awareness of the advantage of embracing circular practices [35].

Effective strategies to surmount these economic challenges require multi-party collaboration, innovative business models and metrics, and technology adoption [35]. This collective effort should produce clear economic incentives, practical solutions, standardised metrics, and increased market demand for circular products. Thus, through collaborative efforts between stakeholders and government support, circular economy implementation can become a tangible reality in the built environment [37].

1.6 Success Factors for Circular Economy Implementations in the Built Environment

The transition towards a more sustainable and circular future in the built environment requires addressing various factors that minimise waste generation, resource depletion, and environmental impacts. Collaboration and stakeholder engagement are crucial, involving architects, designers, contractors, legislators, manufacturers, and communities at every stage of the value chain [12]. Design for adaptability and modularity is essential, building flexibility and modularity into designs to make disassembly, reconfiguration, and reuse easier, avoiding total demolition and reconstruction for future adjustments and additions [35].

Careful consideration in material selection is critical, prioritizing durable, highly recyclable, and environmentally friendly materials.

Resource-saving practices such as energy-efficient systems, sustainable landscaping, and water-saving technology further enhance the circularity of built environments. Taking a lifecycle approach to building, from planning and construction through use and eventual destruction, is crucial. Efficient asset management measures such as routine maintenance, monitoring, and upgrading increase the lifespan and value of buildings [12].

Creating circular business models that incentivise recycling, renovation, and remanufacturing of building materials promote longer product lifecycles and decreased waste production using leasing, sharing, and product-as-a-service models. These circular practices may be financially incentivised through tax breaks or subsidies [35].

Data management and digitalization play a pivotal role in promoting effective decision-making throughout the building lifespan, reducing waste, and allocating resources better. Building Information Modelling (BIM), Internet of Things (IoT), and data analytics are some digital technologies that can be used [38].

Governments and regulatory agencies promote circular economy adoption through supportive policies, laws, and standards, such as waste management regulations, green construction accreditations, and procurement policies that prioritise circular practices [39]. Encouraging public education and knowledge about the benefits and significance of the circular economy in the built environment among experts, decision-makers, and the public is critical in promoting a culture of sustainability and embracing circular practices.

1.7 General Conclusions and Future Trends in Circular Economy Practices for the Built Environment

The built environment industry is exploring the circular economy concept as a way to reduce resource consumption and move away from the traditional linear take-make-dispose model. The circular economy aims to create maximum economic value while minimizing waste by applying circular principles to both existing and new buildings. These principles include adaptive reuse, prefabrication, and modular construction. According to a report by the Ellen MacArthur Foundation, the circular economy offers significant investment opportunities of 115 billion euros for Europe's built environment sector. These opportunities involve designing and building circular structures, establishing closed-loop systems for construction and demolition materials, and creating circular cities [23].

However, the implementation of circular economy practices in the built environment faces several challenges, such as policy and regulatory barriers, information and awareness gaps, and the need for more collaboration across the supply chain. Despite these challenges, several trends are emerging in the circular economy practices of the built environment industry, such as increased awareness, technological and material innovation, stakeholder collaboration, and policy support from governments and regulatory bodies [5].

The built environment industry is moving towards a more sustainable and circular future, with several promising aspects emerging. These include the increased use of modular and prefabricated construction methods that enable easy disassembly, reuse of components, and repair instead of replacement [34]. These methods can reduce waste and resource consumption, as well as increase flexibility and adaptability. Another aspect is the integration of circular principles into energy, water, and waste systems for entire buildings and neighbourhoods. This can create more efficient and resilient systems that minimise environmental impacts and optimise resource flows. A third aspect is the availability of recycled, repurposed, and reclaimed building materials that can reduce the demand for virgin materials and extend the life cycle of existing materials. A fourth aspect is the application of digital technologies to support circularity, such as building information modelling (BIM), material passports, and blockchain-based supply chain management [35]. These technologies can enhance transparency, traceability, and quality of building materials and components, as well as facilitate circular design and decision making. A fifth aspect is the incorporation of circularity into disaster recovery and resilience planning in the face of climate change [12]. This can help the built environment industry to prepare for and respond to natural disasters, as well as to recover and rebuild in a more sustainable and circular way. The adoption of circular economy practices in the built environment is essential for promoting sustainability and reducing waste. Continued innovation and collaboration across the industry will be necessary for these practices to become the norm and create a more sustainable future for us all.

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