Chapter 1
Circular Construction Principles: From Theoretical Perspective to Practical Application in Public Procurement

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Abstract This paper aims to highlight the role of government and other public authorities in promoting the implementation of circular economy principles in the built environment. Circular construction ecosystem is based on circular building design and the coordinated action of stakeholders along the value chain. Government and local authorities have a special role to play in the built environment as they manage infrastructure and act as regulators and enablers as well. Moreover, circular building design strategies should be encouraged through the government policy tools like public procurement allowing public authorities to formulate tenders that incorporate circular economy principles when purchasing goods, services, and works related to the built environment. The case studies presented show that public procurement can be a valuable tool for promoting circular use of materials and reducing waste, encouraging the construction of circularly designed zero-emission buildings, and stimulating market innovation that reduces the environmental impact of construction while providing benefits to society. Thus, public authorities can be a powerful force driving change and innovation in the construction industry towards more circularity in the built environment.

Keywords Circular construction · Circular economy · Public procurement

1.1 Introduction

According to the European Commission [1], the full life cycle of buildings in the European Union (EU) including extraction, manufacture, transport, construction and end of life accounts approximately for 50% of the total energy use, 50% of the raw material extraction, 40% of the total greenhouse gas emissions, and a third of all water consumption and waste generated. There is a need to break this vicious cycle

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and create a new one by applying the circular economy principles in construction. Key elements of circular construction are circular design and the circular use of materials that stimulates the application of reused and bio-based materials [2, 3].

The way a building is designed and constructed has a crucial role regarding its environmental and social impact over its life cycle and the potential for new life cycles [4]. Circular design enables creating a sustainable built environment by making buildings more adaptable and facilitates the high-value reuse of a structure's products and materials at the end of their life [3]. Reversible building design is design of buildings which can be easily deconstructed, or where parts can be removed and added easily without damaging the building or the products, components or materials, thus focusing on their future use [5, 6]. Different layers like windows, floors, inner walls, ventilation can be accessed without damaging other parts of the building enabling resource efficient repair, replacement, reuse, and recovery of products, building materials, and components [6]. Durmisevic [7] presents a new philosophy where reversible building design means designing for circular value chains, while construction and demolition waste is considered a design error. She identifies three dimensions of reversibility within a building—spatial, structural, and material which should be integrated into the building's design to ensure high transformation capacity and reuse potential of building and its structure.

However, the implementation of the circular economy in the built environment is possible only through coordinated action of all stakeholders involved in the circular construction ecosystem. The aim of this paper is to present the role of the government as a key stakeholder that can use its purchasing power to promote circularity in the built environment.

The remainder of this paper is structured as follows. Section 1.2 presents different circular design strategies as part of the circular construction ecosystem. Benefits and challenges of the circular construction ecosystem are described in Sect. 1.3. In the fourth Section two case studies will be presented to demonstrate the role of public procurement in promoting circular construction. The final section contains concluding remarks.

1.2 Circular Design as a Foundation of Circular Construction Ecosystem

Circular design is the centrepiece of the circular construction ecosystem. Not only that it influences the carbon footprint of the built environment and its users, but it can also allow adaptation to changing use patterns [8]. Ellen MacArthur Foundation and Arup have developed the circular design framework [9] encompassing design for longevity, design for adaptability, and design for disassembly as different approaches to circular design of buildings (Table 1.1).

Design for longevity seeks to achieve timeless architecture while using durable products and materials that can be adapted and reused in the future [10]. Longevity

Table 1.1 Circular design strategies [10]

Circular design strategy	Description
Design for longevity [10]	Aims at maximizing the value of the building and its components over time, optimising value retention and value recovery potential. It ensures a long-life cycle of components by setting the baseline for an element's quality, maintenance need, necessity for repair, adaptability and residual value when removed
Design for adaptability [10]	Aims at enabling buildings to adapt to new functions during the use stage to retain their value, which is especially important considering the short functional life span of buildings
Design for disassembly [10]	Allows for the practical disassembly of components in order to recover residual value at the end of their service life

allows the resources used in building construction to last a long time, thus contributing to the circular economy by slowing down the loop [11].

Design for adaptability enables building to redefine its purpose without major interventions and to use considerably less material compared to major renovation, it reduces the need to demolish and avoids a considerable amount of construction and demolition waste [8]. Adaptable buildings can undergo spatial change and functional changes during its lifespan, thus allowing for multiple life cycles [3]. Increased adaptability is provided by using of modular concepts, easy-to-change façades allowing for changes in building appearance and functionality, and plug-and-play technical installations [8].

Design for deconstruction and disassembly facilitates deconstruction of a building at the end of its useful life, in such a way that components and parts that outlast their service life as part of a system (building) can be recycled, reused, or recovered for further economic use [10, 12]. Bertino et al. [13] suggest that the building deconstruction can be facilitated by reducing building complexity through favouring the modularity and lightness of the components, prefabrication and the simplification of the connections between the structural and non-structural elements, and minimizing the number and types of components; choosing reusable and eco-compatible materials whilst minimizing the use of hazardous and composite materials; and providing the information on the building construction and deconstruction. Deconstruction also includes securing the current construction, the analysis of building's contents, the decontamination and removal of any hazardous waste, the demolition activities and the recycling operations to recover the value of the existing materials [12].

During construction 10–15% of built material is wasted, 54% of demolition materials are landfilled, while most materials are not suitable for reuse due to toxic elements [14]. Circular material use in construction is based on principles of maximizing the use of virgin materials and bio-based materials, maximizing the potential for high-value reuse and the amount of recycled materials used [3]. In 2021, the estimated circular material rate in the European Union was 11.7%, which leaves plenty of room for improvement, especially considering that the circularity rate recorded in Netherlands was 33.8% [15].

Sustainable circular construction adds to the circular construction ecosystem by including the social component and presents an integrated approach to "design, construction, operation and occupancy, maintenance, renovation, and demolition processes of structures, all of which are environmentally responsible and resource efficient throughout a building's life cycle, limiting the environmental impacts and ensuring optimal efficiency whilst creating a high level of quality of life for its occupants." [16].

1.3 Benefits and Challenges of the Circular Construction Ecosystem

Circularly designed buildings offer several benefits, one of them being the decreased environmental impact, which is especially important in the context of limited resources [3]. In the long term such buildings provide reduced material extraction, reduced embodied carbon emissions, enable future reuse of building components and recovery of an asset's value at the end of its service life [10]. Circularly designed buildings cost less over their life span than traditional buildings because they generate value during their maintenance and replacement phase, entail modular products that can be replaced in parts, interior walls that can be moved (enabling flexibility and adaptability), and avoid demolition costs due to detachability [3].

Two main challenges for the first use of circularly designed buildings are that they may require higher material quantities and may result in higher environmental impact [10]. However, over the full life-cycle these materials would provide benefits because they could be reused, replaced or recycled, thus reducing negative impact on the environment. Real challenge lies in persuading the stakeholders (Fig. 1.1) to embrace circular business models and the full life cycle approach that goes beyond economic cost of the building construction and considers environmental aspects as well. European Commission [12] identifies seven target groups that can contribute to meeting durability, adaptability, and waste reduction objectives in the construction industry: 1. building users, facility managers and owners; 2. design teams (engineering & architecture of buildings); 3. contractors and builders; 4. manufacturers of construction products; 5. deconstruction and demolition teams; 6. investors, developers and insurance providers; and 7. government/regulators/local authorities. In order to facilitate the future circular use of building materials, stakeholders should be familiar with the concept of circular construction and an integrated approach along the value chain is needed [12].

Carra and Magdani [17] stress the importance of developing integrated value chains in providing following competitive advantages for the companies in the future. Building users, facility managers and owners will benefit from an increased value of their assets due to more efficient, productive, and adaptive spaces [17]. Investors will

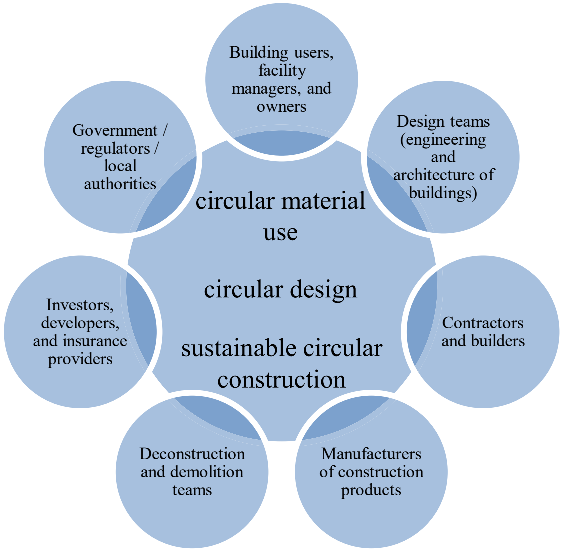

Fig. 1.1 Circular construction ecosystem (based on [3, 12])

benefit from the increased value of the space which can be quickly adapted to the demands of new tenants, thereby minimising the period of vacancy [17]. Designers will need to ensure building design that allows for durability, disassembly, and adaptability by working closely with product manufacturers and suppliers [17]. The use of materials and products that can be recycled and reused should be foreseen in the planning stage of a renovation or a new building in order to be designed and built as a resource bank [2]. Designers need to consider the whole life cycle of the building from the decision to build new or refurbish to the eventual demolition or deconstruction of an obsolete building [16]. The possibility of on-site reuse of reclaimed building materials should also be considered by architects during the renovation design process [18].

Contractors and builders will need to ensure users, facility managers and developers implement the circular solutions during the building lifecycle [17]. Manufacturers and suppliers have an opportunity to earn additional income by recovering materials at the end of a product's life and reselling or repurposing them [17]. Deconstruction and demolition teams will have an opportunity to become material reuse providers and potentially join forces with material extractors or producers to ensure a continuity of supply. [17]. Prior to demolition, material inventory should be made through audits to properly identify quantity, dimensions, technical function, maintenance, and the presence of harmful substances in the materials [2].

Public authorities manage large building stock and urban infrastructure, and act as regulators and enablers through zoning and permitting [2]. Raph [8] suggests that future regulatory European Union initiatives addressing buildings should encourage the construction of adaptive buildings that are aligned with circular economy principles and ensure that major renovations take adaptability into account. Design teams should discuss the future strategy of the building with local authorities to ensure reconfiguration is possible by using a modular approach allowing for easy disassembly and assembly of components [17]. According to Bilal et al. [19], there is a lack of public awareness and support from public institutions, while the lack of environmental regulations and laws triggers other barriers to the circular economy. Giorgi et al. [20] suggest that the circular economy policy development in the construction industry should involve all stakeholders and emphasise the need to define and harmonize design strategies for reversible buildings, preferably within a regulatory system. Moreover, such strategies should be encouraged through the government policy tools like public procurement allowing public authorities to formulate tenders that incorporate circular economy principles related to the built environment.

1.4 Case Studies on Promoting the Circular Economy in the Built Environment Through Public Procurement

These two case studies present good practice and provide an overview of how public authorities can promote the reuse of building materials and design for circularity. Although selected by the European Commission as examples of green public procurement [18, 21], they also include a social component, demonstrating that public procurement can serve as an important tool for promoting social inclusion and achieving other benefits that improve the well-being of society.

In France, circular construction principles were implemented in public procurement by setting reclamation targets in a redevelopment tender to ensure the reuse of materials. The public developer SERS (Société d'Aménagement et d'Equipement de la Région de Strasbourg) was supported by the non-profit organization Rotor to find the market for reclaimed materials. As a partner in the Interreg project "Facilitating the circulation of reclaimed building elements in Northwestern Europe", Rotor had access to hundreds of companies dealing with reclaimed building materials. The various steps taken with the help of an expert included creating an inventory of reusable materials, conducting dismantling tests, and performing a market study to identify companies interested in reclaiming the materials from an old building dating from the 1930s. As a result, the contracting authority integrated ambitious reclamation targets in its call for tenders, providing general guidance on reclamation and reuse (dismantling and conditioning tips, useful tools, references, etc.) in annex. The reclamation audit contained three different categories [18]: (A) most promising materials (present in large quantities in the building and with high reuse potential confirmed by the dismantling tests and/or stable market demand for these materials); (B) materials with an estimated reuse potential (for which the potential was not further investigated and/or present in smaller quantities in the building); and (C) other materials (with low reuse potential depending on specific opportunities rather than stable market demand). The reclamation targets for three major batches of materials with very high reuse potential (Category A) were formulated as technical specifications: 1. cast-iron radiators, for which at least 80% of the pieces had to be reclaimed for reuse; 2. structural timber in the roof, for which at least 50% of the total volume had to be reclaimed for reuse; 3. enamelled wall tiles, where at least 50% of the surface area had to be reclaimed for reuse. An award criterion related to the reclamation efforts encouraged bidders to commit to achieving better reclamation rates than the minimum specifications for the three main batches of reusable materials, but they could also commit to reclaiming other batches from Categories B and C, which included metal stairs, handrail, guardrail, antique windows, lighting, doors, and sanitary equipment. A social clause was also included to help people who have difficulty finding work to access employment or return to work. The minimum number of hours for an integration activity was set at 300, but the bidders knew that proposing more hours would improve their score. Before submitting their bids, candidates had the opportunity to visit a site. Ultimately, four bidders submitted an offer and complied with the minimum requirements. The sale of the materials was implicitly factored in the offers as the bidders had to set their prices taking into account the possibility of selling the materials afterwards. Demolition companies with less experience in reclamation found it more difficult to estimate the potential retail value of the batches of reclaimed materials, so the price of some operations, such as dismantling of the structural timber varied considerably. The winning bidder submitted an offer that was the best value for money. Although they had committed to reaching the minimum target, they managed to outperform the initial plan and more batches of dismantled materials could successfully be reclaimed for reuse. They subcontracted the integration structure in charge of dismantling the wall tiles for 328 hours. Finally, 51 tons of materials could be reclaimed for reuse and most of these materials were purchased or recovered by professional dealers who ensured their subsequent resale. The environmental benefits go beyond the waste reduction as the reuse of materials avoids the raw resources extraction and the associated greenhouse gas emissions [18].

In the Czech Republic, the Supreme Audit Office (SAO) decided to build its first permanent headquarters reusing a brownfield land in the centre of Prague. The SAO will share the building with the Parliamentary Library and the Archives of the Chamber of Deputies and will offer their services to the public [22]. The project was driven by the SAO's desire to lead by example and promote the construction of a public building with net-zero energy consumption, the lowest life cycle costs (LCC), and the longest service life. The implementation of circular building design principles is reflected in the flexibility and adaptability of spaces, which are also accessible. The building should also provide modularity in terms of control and replacement of utilities, and the floor designed to allow easy access to utilities. Prior to launching the tender, the project team consulted with academic experts at the Czech Technical University regarding the evaluation of the building's service life and maintenance costs, and conducted two preliminary market consultations [21]. The innovative approach to public procurement was reflected in the first major public project in the Czech Republic to be realised in accordance with the Fédération Internationale des Ingénieurs-Conseils (FIDIC) Yellow Book for Design & Build, and to use Building Information Modelling (BIM) methods for the evaluation of LCC of the building [22]. According to PORR a.s. [23], the company that was awarded the contract, it has relied on BIM technology for many years to give users a complete overview of all relevant aspects of a project and add value to the entire construction value chain. It highlighted that when all project stakeholders use the same model, design aspects and dimensions can be viewed in the context of the entire project life cycle [23].

The SAO published three separate tenders for the principal architect, the civil engineering company, and the construction company. Because it was not easy to meet the innovative requirement of prior experience with BIM projects, SAO required evidence of experience with six separate segments of BIM. The traditional approach to procurement of construction projects, with separate tenders for a designer and a contractor, was replaced with the Design-Build tender providing a single point of responsibility to reduce risk and overall cost. The SAO received four bids and the construction company PORR a.s. won the tender due to its low bid price, although it was the second best in terms of LCC criteria. The winner stated that it was able to offer a price 13% lower than the estimated value of the public contract due to its long experience with the Design-Build method and the ability to manage the implementation of the construction using the Design-Build method supported by BIM, the professional team of in-house designers or close cooperation with design offices whose professional experience is related to practical implementation, and the favourable prices of suppliers [21]. During construction, all stages of the project documentation are processed in BIM and a detailed digital model is created, which enables the use of a drilling robot that transfers the data from the model directly to the building structures. The use of a drilling robot on the construction site significantly speeds up the process of drilling holes in a monolithic structure and marking the holes for each type of pipe. PORR a.s. uses augmented reality to easily check the accuracy of the work performed [24]. In addition, BIM facilitates the use of material passports, which contain valuable digital information about all building materials used. Finally, environmental and social benefits can be achieved (Table 1.2) through good contract management and communication between the contracting authority, the architect, and construction company [21].

This project showed the importance of collaboration with academic experts. The experts from the Faculty of Civil Engineering developed the methodology for calculating the LCC which in this case included operating costs, renovation costs, and maintenance costs for 30 years. Finally, they verified the costs calculated by all four construction companies that submitted their bids.

Preliminary market consultations proved very useful as they allowed potential suppliers to prepare bids or prepare for recycling, sale and reuse of materials, while public authorities could inform the market of their intentions, receive feedback from the market, and prepare the procurement procedure [18, 21]. In the latter case, it became clear that the market was not ready to meet the intended requirement of submitting bids in the BIM form due to a lack of standards and problems with handing over the BIM original format [21]. Innovative and smart solutions need time to overcome problems related to new technologies and market developments. However, public procurement should not be merely a financial and administrative task, but a means of finding sustainable solutions that meet the needs of communities

Table 1.2 Benefits for the environment and society [21]

Environmental benefits	
Resulting from the construction process:	The use of recycled concrete from the previous structures on site; Using a concrete facility on the nearby river bank and transport by water; The use of sand from the construction pit for the construction itself; Saving 22.5 tons of CO_2 through sustainable construction; Wireless lighting control saved wiring material
Resulting from the design phase using BIM:	The building will consume almost net-zero amount of energy; Smart heating and cooling system with thermohydraulic solutions, supplemented by heat recovery, stored in the summer; By determining the ratio between the glazed and the fixed part of the façade, complemented by external, centrally controlled blinds, it is possible to optimise the light and heat quality of the interior, saving energy and money and reducing pollution; Green roofs will benefit the top floors, provide additional thermal insulation, and will also be useful for neighbouring buildings
Social benefits	
Benefits for the employees:	Openable windows in offices; The Child Care Centre will serve as a benefit for employees with kids facilitating their return to work after parental leave; Charging stations for electric cars and e-bikes in the parking lot; A fitness centre shall improve health and well-being of employees; Accessible facilities will allow institutions to easily employ people with disabilities (with light signals for emergencies complementing sirens)
Benefits for the neighbourhood:	New SAO headquarters will contribute to the revitalisation of the area; The area will be walkable with a small park open to the public; The Parliamentary Library, the Archive of the Chamber of Deputies, and the cafeteria within the building will be available to the public

and create a better quality of life for all. Given that this paper focused on the good practice of selected public institutions, future research could explore the potential of local government procurement practices to demonstrate how cities can contribute to the implementation of the circular economy in the built environment.

1.5 Conclusion

Circular building design lies at the heart of the circular construction ecosystem. Translating circular economy principles into design enables the construction of buildings that last longer, produce less waste, facilitate management and maintenance, and allow for the reuse or high-quality recycling of major building components.

Implementing the circular economy in the built environment requires an integrated approach by all stakeholders along the value chain. Governments and local authorities have an important role to play in circular construction as they manage a large building stock and urban infrastructure, and act as regulators and enablers as well. Public authorities can also encourage demand for circular design of buildings and secondary materials through public procurement and benefit from allies such as reclamation audit experts and academic experts during the tendering process.

The case studies presented show that public procurement can be a valuable tool for promoting the circular use of materials and reducing waste, encouraging the construction of circularly designed zero-emission buildings, and stimulating market innovation that reduces the environmental impact of construction while providing benefits to society. In this way, public authorities can be a powerful force driving change and innovation in the construction industry towards more circularity in the built environment.

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