Circularity and sustainability in the construction value chain

P Huovila[1] * and N Westerholm[2]

[1] Sustainability Laboratory Oy, Helsinki, Finland
[2] Tampere University, Faculty of Built Environment, Tampere, Finland

*pekka.huovila@slab.fi

Abstract. This paper debates how circularity can contribute to value creation in the construction value chain. In traditional linear business models, value is often limited to financial value for the firm and customers. Here, value is seen more broadly considering a wider range of stakeholders, such as value chain partners, the environment, and the society. Findings from relevant literature and recent research projects are brought to transform linear cradle to grave processes to sustainable cradle to cradle ones. Circularity can contribute to sustainability in many ways: material recovery from existing buildings and reusing, recycling or even upcycling them into new ones and design for disassembly that eases reuse and value retention. Findings indicate that circular economy has significant potential to create and maintain value in the construction value chain. Most of the decisions that affect value creation are done in the design stage, but it is strongly linked to the other stages and affected by business models, circularity platforms, and external influencers such as financing, client's requirements, regulations and incentives.

Keywords: buildings and construction, business models, circular economy, construction value chain, sustainability

1. Introduction

The buildings and construction sector is an important contributor to environmental impacts and wealth creation in the society having also social consequences. Globally, construction uses 36 % of the energy, produces 39 % of emissions [1], up to 40 % of waste [2] and uses 50 % of all the extracted materials [1]. Raw material extraction and processing causes 90 % of biodiversity loss [3]. Whilst this is happening, it is estimated that only 9 % of the extracted resources are circular, meaning that is how little is re-used annually [4]. These numbers underline the need for change in the construction sector during a time when we are facing both climate emergency and biodiversity crisis, both of which are driven by human activities that push beyond the planetary boundaries. A transition from the now dominant linear economic model towards circular economy, where human activity adheres to planetary boundaries, could be the much-needed solution to our challenges.

We spend most of our time inside of buildings. In North America and Europe, people spend almost 90 % of their life indoors [5,6]. Additionally, the construction sector provides work for 7,7 % of the global workforce [2]. Hence, the construction sector also has not only great environmental but also social impact. Moreover, the construction sector contributes to 13 % of the global GDP [7]. However, the negative environmental impacts are enormous in relation to positive economic impact.

Since the construction sector has significant environmental, economic and social impact, it is natural that it has potential to create environmental, economic and social value. In traditional business models, value is often concentrated on the financial value for the investor and customers. In business models that are based on circular economy, value is seen more broadly considering a wider range of value chain partners, the environment and the society [8]. Transforming linear cradle to grave processes to circular cradle to cradle processes provides opportunities to material use efficiency, waste reduction and value retention or increase.

This paper presents how environmental, economic and social values can be achieved through circularity. Additionally, it debates how the construction value chain can support the circular transition, who are the actors involved in value creation and which are stages in the construction life cycle where value is created. Based on workshops held for experts involved in construction, the influence external actors have on the construction value chain are mapped. Moreover, this paper discusses how different business models, platforms, etc. can support sustainability by circularity.

2. Construction life cycle stages

EN 15643:2021 defines the construction process in pre-construction (A0), product (A1-3), construction process (A4-5), use (B1-8) and end of life (C1-4) stages adding circularity (D) in benefits and loads beyond the system boundary.

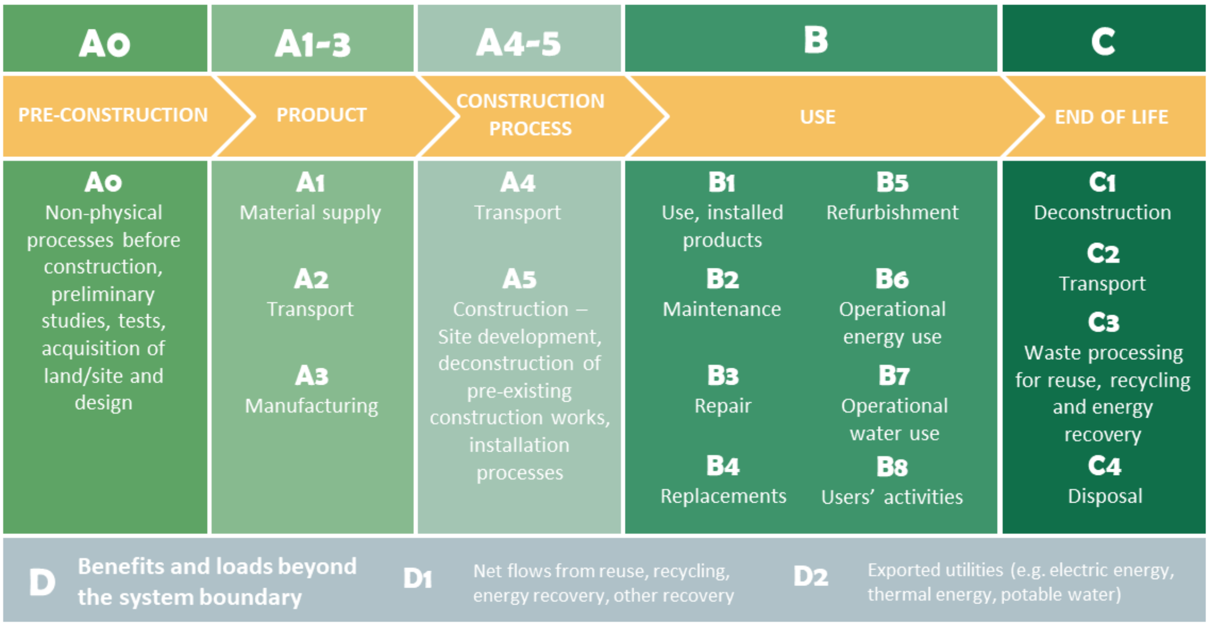

Figure 1. Construction works assessment information in EN 15643:2021. [9]

One Planet Sustainable Buildings and Construction programme (SBC) works on circular built environment. It has looked at it in the following circular life cycle stages, where the process can be started from any of them. The stages are Product manufacture, Design, Construction, Operation & maintenance, Renovation and Deconstruction & End of life. The main actors in each stage are illustrated in Figure 2.

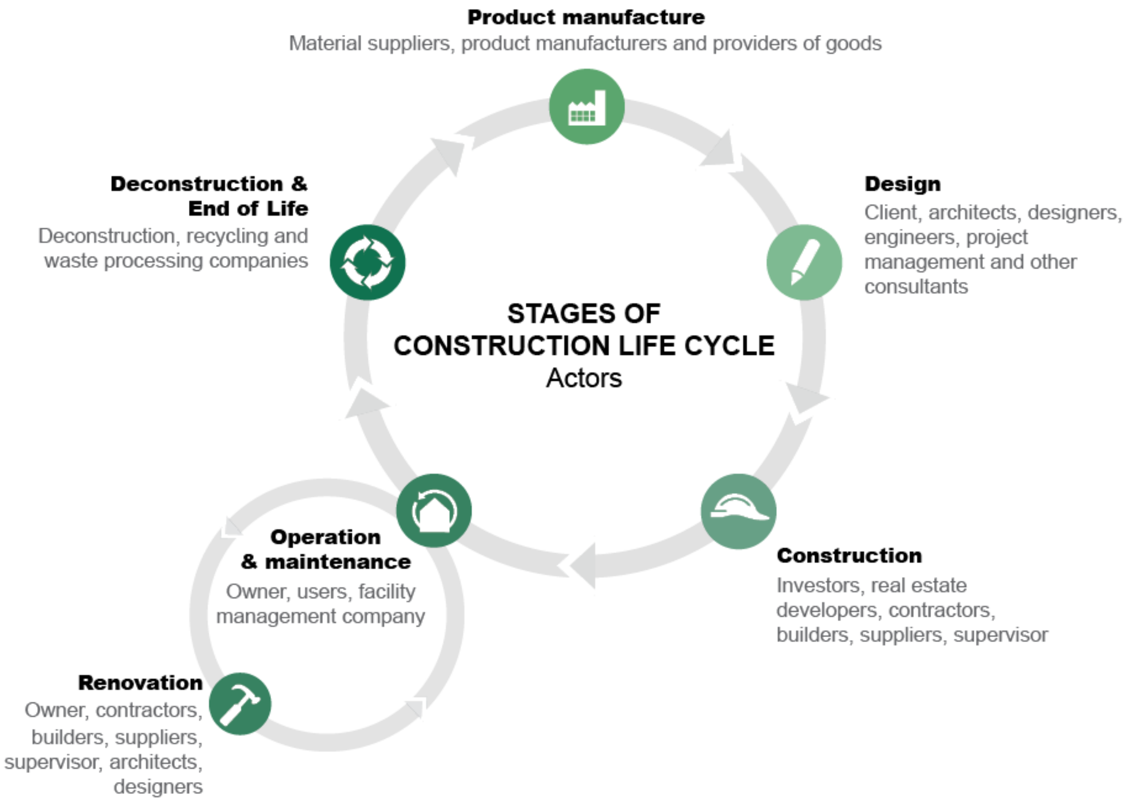

Figure 2. Stages of circular construction life cycle - actors.

3. Construction value chain workshops

One Planet network and the International Resource Panel Task Group (OPN-IRP) has worked on science-based policy action on sustainable consumption and production analyzing the value chain. The purpose has been to carry collectively a number of the primary messages, opportunities, and gaps detected during the collection of professional consultations workshops, in mapping ongoing tasks towards the strategic intervention points. [10]

One Planet network organized three global workshops in 2021 with altogether 90 participating experts within the built environment to look at how public procurement exerts influence construction throughout the construction value chain, how planning and design frame actions along the construction value chain and how financing shapes the construction value chain. Knowledge gained from these workshops is presented in Figure 3.

Governments and multilateral organizations, in which many act as regulators, planners and investors, were identified as influencers of the actions along the construction value chain. Banking and tax system regulation influences in financial markets leading to when and what will be designed and constructed whereas zoning regulates where different building types can be developed.

Public procurement can significantly contribute to improving resource use and environmental impacts in the construction value chain by integrating circular economy already in the project planning phase or early design phase. This can be done, for example, by designing out waste and keeping materials in use and so that they retain their value, and by promoting the use of resource efficient low carbon materials. Additionally, circularity principles in the project brief can address reuse, design, standardization and responsibility. It can include reusing, refurbishing and repurposing of recovered materials and products from the existing assets and making them available for future reuse. Moreover, longevity, flexibility, adaptability, assembly, disassembly and as well as recoverability can be made into design requirements. [11]

Applying standardized elements or modular designs for materials and products can enable reduction in construction waste and easier reuse in the next life cycle. A transition from selling products to selling services supports circularity. Responsible design and construction favor secondary materials, materials with high recycled content and renewable virgin materials with low environmental impacts. Additionally, they focus on designing out waste and reducing negative impacts of construction. [11]

Urban planners and property developers determine what is going built and where. Planning practices and market engagement vary across different countries. In many developed countries the construction value chain needs to focus on re-using existing buildings and materials whereas there is an need for new construction in developing countries and not enough secondary materials to meet the demand. [12]

A stable and predictable regulatory framework for sustainable construction should attract investment supported by, where possible, financial incentives through taxation or other means. Different project delivery systems, such as design-build-finance-operate-maintain (DBFOM) can influence in how the project is financed. Developing circular solutions in a collaborative way may happen using the Alliance contracting. In Energy Performance Contracting (EPC) energy management can be outsourced and the resulting savings and profit shared.

Finally, capacity building to all actors across the construction value chain supports making more sustainable choices. The lack of sustainability data is an overarching challenge across the construction value chain. Access to reliable data may be incomplete and knowledge to use appropriate tools to support decision making insufficient. Collaboration of all stakeholders to gather and share relevant data is necessary to improve resource efficiency of the sector. It is important to connect research, policy, data and monitoring with implementation and work in practice to learn from each other.

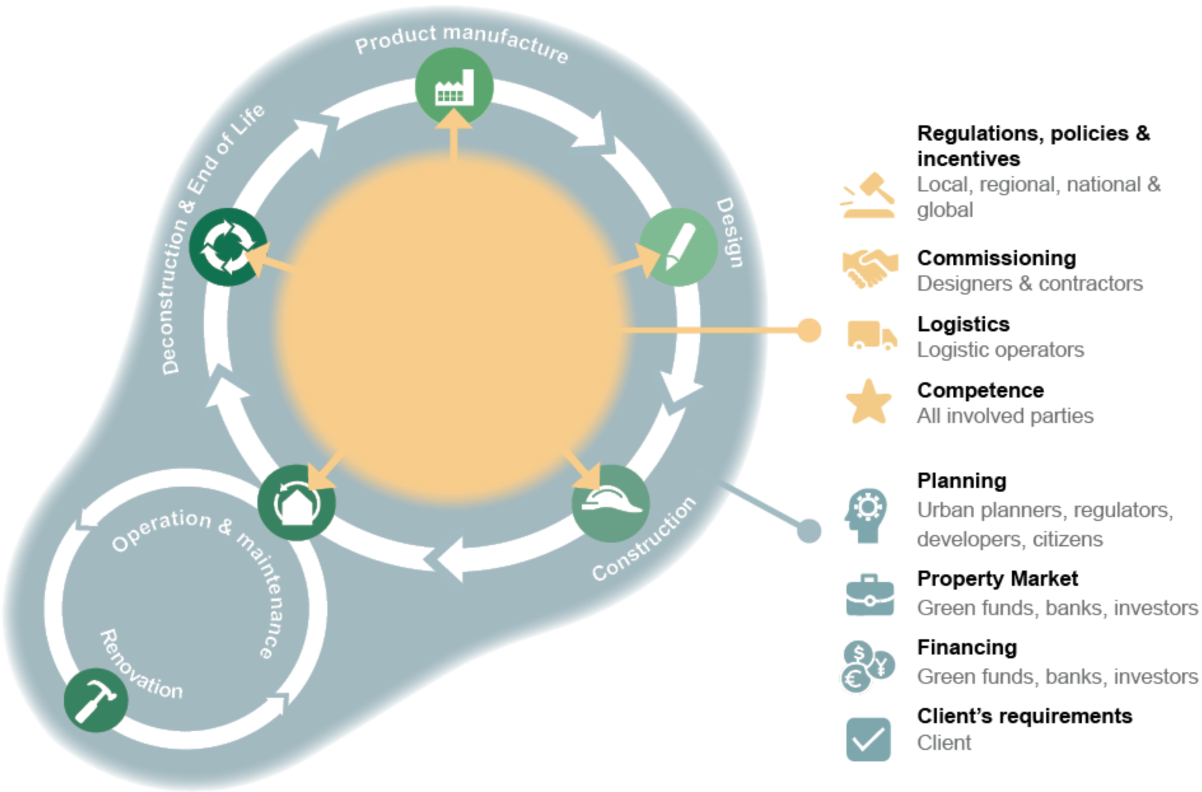

Figure 3. Stages of circular construction life cycle – external actors & playground.

4. Value created by circularity

As stated in the SBC programme's Global State of Play for Circular Built Environment report [12], it is no longer a question *if* the construction sector will turn circular but rather a question of *when* and *how* this transition will happen. Thus, it is relevant to understand what circularity can bring to the construction value chain. Construction has great potential to create environmental, economic and social value. Transitioning to circularity can create value of all three sorts. However, it is important to point out that something that creates environmental value does not necessarily create social and / or economic value, and vice versa. In this section, circular value creation is discussed.

One of the key points in circular construction is efficient reuse of materials. Using secondary materials lowers the need to extract virgin materials, the latter being strongly linked to biodiversity loss and high global warming potential. Efficient reuse also contributes to value retention. Research shows that efficient reuse of construction materials can have great positive environmental impacts. However, the extent of these positive impacts varies depending on the chosen materials and products. [8]. Carbon saving potential, land-use reduction potential, mineral fossil, renewable and water resource depletion and human toxicity, are a few of these environmental savings that adds to the environment value of circular practice [8].

Re-using bricks has a carbon saving potential of 99 % [13] in comparison to the typical virgin brick, windows has a carbon saving potential of 77 % and concrete that used recycled aggregate has the saving potential of 4 %. The carbon saving potential of reusing crushed concrete is small because 91 % of the carbon footprint stems from cement. Even though the global warming potential effects are reasonably small it has other much greater positive impacts. The use of secondary aggregates can reduce the land use needs by 37 %, exhaustion of mineral resources by 30 %, and exhaustion of water resources and human toxicity by 20 %. [8]

Since reuse is connected to many positive effects on the environment, design for disassembly should become the standard. In design for disassembly, buildings are seen as materials banks in which materials are temporarily stored in a way that allows easy disassembly and reuse in the future. Hence, design for disassembly is a promise of value retention.

Applying circularity to construction can also produce financial value in many ways. The price of secondary materials in comparison to virgin materials is typically lower [14,15]. Moreover, circularity helps retain the value of construction materials and products [16–18]. Circular construction is also associated with superior customer value. Research shows that circular implementation is linked to lower life cycle costs when compared to typical linear solutions [19,20]. However, sustainable construction is still perceived to have higher initial investment costs [21]. Research shows that sustainable buildings cost only a little more to build than conventional buildings [22,23]. Even if the initial investment costs would be greater, one financial advantage of sustainable construction is that one can charge more for a building with great environmental performance [8]. Sustainable construction can create additional economic value by improving the competitive advantage [8,24,25] and minimizing the financial risk for investors [23,26]. Buildings with low negative environmental impacts might also have positive effects on corporate image and marketing [24,25,27].

Circular construction can also contribute to added social value. Reusing materials is more labor intensive and thus it creates employment [28]. Additionally, circular construction favors repurposing and redesigning existing spaces instead of tearing them down and building new. This allows the preservation of historical architecture and cultural heritage and identity.

In many cases, the factors that contribute to environmental or economic value also contribute to added social value [8]. Good examples are the decrease in toxicity and pollution, since they have positive impact on both the environment and our health. Decreasing carbon dioxide emissions is necessary when protecting the environment but also our well-being. Research [29,30] shows that global warming increases social injustice: the wealthier are polluting more, while the poor are the ones suffering most of the consequences. Thus, climate change mitigation, such as circular low carbon-construction, has the potential to decrease social injustice.

In the case of Merton Regeneration project in London, a complex of 2 800 homes, circular practices created value of all three sorts. Circularity saved the use of 122 000 tons of virgin material, achieved 7 760 tons of CO_2 savings and 16 500 fewer heavy goods deliveries, which is both a saving for the environment, the economy and the society. Additionally, circularity is estimated to result in 6 million € cost savings in waste disposal and material purchase. [11]

In the case of both Recycle Rows and Upcycle studios in Denmark, the circularity approach created 18 new jobs, achieved the fastest sales in the neighborhood and a 6 % decrease in acquisition and maintenance costs. The cost of retrieving the secondary materials used was lower in comparison to typical virgin materials. However, the processing of the secondary materials was costly because circularity at this stage is still an innovative approach. Building these highly circular buildings resulted in 8-10 % higher initial cost. In Upcycle studios, the use of secondary materials resulted in 914 tons less waste and 60 tons of CO2e savings (45 % less emissions than typical construction). In Recycle Rows, the use of secondary materials resulted in 463 tons less waste and 20 tons of CO2e savings (29 % less emissions than typical construction). Additionally, Recycle Rows reused the bricks of the local historical breweries in its facades and thus linking the new building to the history of the neighborhood. [23]

Circular economy is not only the luxury of the wealthy North. Good examples of circular construction can be taken also from the Global South. Pulluvila Thota Net Zero Campus in India reduced the volume of material and burnt products, reused reclaimed material, recovered and recycled C&D waste with overall reduction of steel by 50 % and cement by 30 %. [31] Another pioneer project is BioHotel in Colombia: 70 % of the needed materials are construction and demolition waste from pre-existing buildings, 60 % of the used soil is excess from excavation sites for building materials, and for operation it needs only 50 % of water in comparison to typical buildings because of efficient devices, and the collection and use of both rainwater and gray water. [32]

4.1. Value creation in the circular construction value chain

The transition from linear to circular economy needs systemic transformation, something that can be hindered when actors in the value chain are not fully aware of the role they are expected to undertake, especially when it comes to execution [8]. Hence, it is important to ask who are the actors and in which stages will sustainability be achieved and maintained, thus value created? The SBC programme has described its view in Figure 4.

In the Product manufacture stage material suppliers and product manufacturers produce safe resource efficient goods with low carbon footprints and high recycled content. Additionally, these products have a long lifespan, and they are easy to maintain, remove, and replace. This stage favors reused products, secondary materials and renewable virgin materials with low negative environmental impacts. Product manufacturers are also responsible for creating digital material passports that capture and store information on the materials used, which makes creating and maintaining value easier in the other stages. Making sustainable and circular materials and products available is necessary so that other stages can achieve the desired outcomes and added value.

In the Design stage architects, designers, engineers, project management and other consultants create sustainable and adaptable designs that ensure disassembly and designs that meet the needs of the owner, changing users and the society. The designers select sustainable materials made available by the previous stage to be used in the construction stage. A circular building requires more planning and careful design. Besides planning how the building will be constructed, a plan of how it will be deconstructed should be made. Additionally, in comparison to linear construction, more people and a wider set of expertise need to be involved in the design stage. When designing for disassembly, co-operation between designer and other value chain partners is crucial to ensure that the value of the materials will be retained. The design stage also utilizes digitalization in many ways. Actors in this stage create both collaborative BIM models and building passports that help capture, store and share building related data. Additionally, new tools such as 3D scanners make it easier for the designers to select reused materials. Europe is the region furthest along when it comes to both circular economy and digitalization in construction, while it remains far from circular. One of the biggest problems in Europe is that the existing building stock is relatively old and it has not been designed nor built for disassembly, which often makes efficient deconstruction and reuse challenging [33]. The design stage is the most crucial stage when it comes to assuring circularity across the value chain. In the design stage the decisions are made that ensure most of the value, while the next stage, the construction stage, realizes most of this value.

In the Construction stage investors, real estate developers, contractors and suppliers with supervisor deliver zero waste buildings that are safely and resource-efficiently built while also zero defect in time assembly. Prefabrication of elements has significant potential to reduce the construction time (even cut it in half) and the amount of waste produced [34]. Additionally, prefabrication is safer for the construction workers since there is less dangerous maneuvers on-site and most of the work is done in a safe and controlled factory environment. It is noteworthy to point out that out of the waste produced in this stage today, it is estimated that a reduction of 33 % could be achieved with better waste reduction measures in the design phase [35], something further underlining the importance of the design phase.

In the Operation and maintenance stage owners, users and the facility management company keep track of the building's performance and emissions. Additionally, they ensure proper maintenance in a way that the building's value remains. When the needs of the owners, users and society changes so much that changes to the building are required, these needs are expressed so than they can be met in the following stage.

In the Renovation stage, owners, users and facility management company realize the needed changes safely, resource efficiently, with zero waste and zero defect in time delivery. Additionally, the building passports are kept up to date.

In the Deconstruction and end of life stage deconstruction, recycling and waste processing companies contribute to upcycled, re-used and recycled products with treated waste.

Even though the value chain in split into six stages, one phase does not begin where the former ends. Regarding time, these stages often overlap and may be strongly intertwined. With proper building passports, the parts from a building that has been set for deconstruction can already be considered in the design phase of another building, etc. Hence, fluent communication and cooperation between the actors in the different stages is crucial.

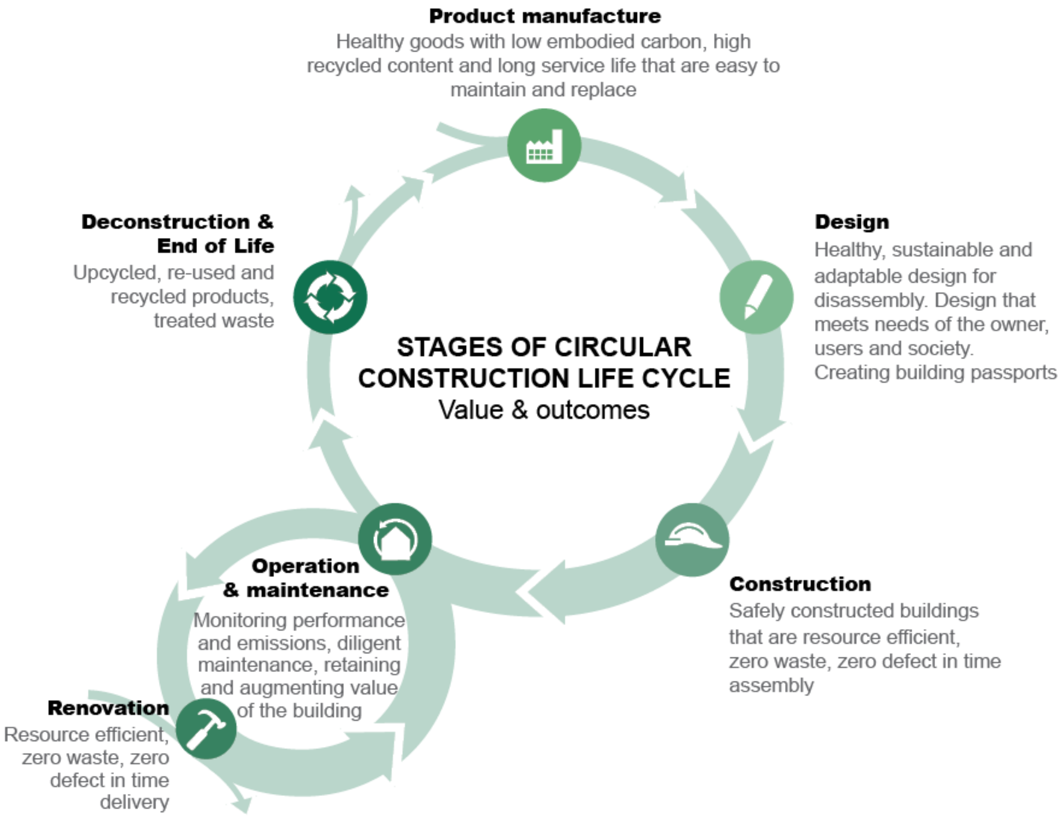

Figure 4. Stages of circular construction life cycle – value & outcomes.

Based on presented research, we have depicted the key outcomes of circularity across the construction value chain in Figure 4. Additionally, the figure shows in a simple manner how value increases and decreases in the circular value chain. It is based on the notion that construction products have certain value. Through circular design and construction, these products are used to construct a facility. This building has greater value than that of the products used. When the building is designed and built to meet the needs of both owners, first users and society, its value is at its highest. During the operation and maintenance phase, the needs start changing and thus the value of the building starts to decrease, unless or until the building changes (renovation phase) so that it will again meet the needs of both owners, users and the society. The renovation phase extends the service life of the building. If there comes a time when the building can no longer respond to changing needs, it will be deconstructed and its value will collapse. However, efficient deconstruction allows reuse and recycling of the materials and products and because of that, value can be retained and transferred to the product manufacture stage and enter a new life cycle.

Developers, investors and financiers based on their market knowledge influence the process affecting sustainability where green funds may have their role. There is a rising trend of green investing. According to the PGIM survey, 58 % of global investors intently integrate environmental responsibility in their investment strategies [36]. This is also something the European Green Deal promotes, since it aims to transform the EU climate neutral by 2050 in a way that benefits both citizens and businesses [37]. Continuous learning is needed from all actors ensuring that required competence can be exploited during the long service life of buildings. Business models spanning present and future actors across circular stages need still to be further developed. Trust needs to be created so that we can move to sub-optimization to a situation where value and benefits can be quantified and also shared in a way it is defined in the contracts.

4.2. Circular business models and platforms

WBCSD has defined five circular business models: Circular supplies for material use minimization, Products as a service supported by emerging business models, Product lifetime extension to reuse, maintain and refurbish over recycling, Sharing platforms for industrial symbiosis and sharing economy and Resource recovery for extended producer responsibility [23,38].

Town Hall of Brummen is an example of a circular business model and design for disassembly, a case in which circularity is of great environmental and economic value. The municipality needed a town hall, but for how long was uncertain. Thus, the building was leased with a service contract for 20 years. The building was designed in a way that allows for 90 % of the materials to be easily dismantled and returned to the suppliers. At the same time, the owner will gain back at least 20 % of the building components' original economic value. [26]. The estimated total cost of the project was 30 % cheaper than two similar town halls in the area [20]. The circular business model managed to make it a less risky investment in comparison to typical solutions. This cost estimation considered the expected 20-year long occupancy period [20,26].

We need ways to keep our materials in the loop, but we also need to create a market for them. Hence, there is a growing need for platforms that connect secondary materials with customers. Rotor Deconstruction, Loopfront, Allô Gravats and DigiYard are such examples. Rotor Deconstruction is a Belgian company that evaluates the possibilities of reuse in buildings before their end of life. Additionally, they make the material information available for potential buyers before the deconstruction of the building. Deconstruction that allow efficient reuse is made cost neutral for the building owners by using the income from sales of the secondary materials to cover the extra expenses [39]. Norwegian Loopfront has created a digital platform that increases the collaboration between actors in the value chain, maps and registers materials and works as a marketplace for reused building materials [40]. Allô Gravats is a construction and demolition waste elimination action created by the Senegalese government. Companies, communities and individuals can access the digital platform to request for debris abolishment. The service removes the waste for a charge and transports it to a recycling facility where the waste is taken care of and recycled [41]. DigiYard service links small scale, and regularly informal, contractors with leftover building materials from construction sites in South Africa. The phonebased platform permits developers in South African townships to acquire well performing construction materials at low-price and to get right of entry to trainings on safe building techniques and correct assembly of building components. It additionally prevents the construction waste from larger sites from being despatched to landfills. The utility is free and is presently piloted and improved. [41]

5. **Discussion**

This paper has explained how circular economy contributes to sustainability and how it affects the construction value chain. It presents what kind of value is created and pinpoints the, from the circularity point of view, most critical stages and actors in the value chain. It can be concluded that most of the decisions that affect the value creation are made in the design phase. However, the external actors that were presented in Figure 3 influence the entire value chain, especially the design stage, and they can support, promote or hinder circular value creation in various ways.

The client has an important role in setting targets to circularity and sustainability that the design team can accomplish supported by material providers and manufacturers. Including circularity in the client's requirements creates a framework in which it is much easier for the value chain partners to realize a circular project and maximize value creation. Collaboration of all actors is needed to ensure achieved performance and desired impacts during the life cycle of buildings. External actors can support or promote circularity also through legislation. For example, legislation that makes life cycle assessment obligatory and gives buildings carbon limits directly forces this to be considered in the design stage. Another example from financing: if life cycle costs are in focus instead of initial costs, the scale tips in favour of more sustainable design.

The regulatory framework should support utilization of re-used, recycled or even upcycled building products. Tools to help high value recovery of deconstructed buildings would be of use. Capacity building is still needed to clients and the whole supply chain to learn new skills. Individual examples have shown that many solutions have successfully been realized. However, business models need still to be developed to explore these opportunities and to mainstream circular transition that can lead to new job creation. Additionally, more roadmaps like the European Green Deal are needed to turn construction circular on a global level.

Pointing out that the external actors have a role to play in the transition to circular economy does not free the actors within the construction life cycle stages from the responsibility to change their practices in line with circular goals. It is possible to achieve remarkable change within the construction value chain without a push from external actors.

References

[1] Global ABC, IEA and UNEP 2019 Towards a zero-emissions, efficient and resilient buildings and construction sector. 2019 Global Status report
[2] UNEP 2009 Sustainable Buildings and Climate initiative
[3] IRP 2019 Global Resources Outlook 2019: Natural Resources for the Future We Want
[4] Circle Economy 2019 The Circularity Gap Report: Closing the Circularity Gap in a 9% World
[5] European Comission 2003 Indoor air pollution: new EU research reveals higher risks than previously thought Eur. Com. IP/03/1278
[6] Klepeis N E, Nelson W C, Ott W R, Robinson J P, Tsang A M, Switzer P, Behar J V., Hern S C and Engelmann W H 2001 The National Human Activity Pattern Survey (NHAPS): A resource for assessing exposure to environmental pollutants J. Expo. Anal. Environ. Epidemiol. **11** 231–52
[7] Oxford Economics 2021 Future of Construction - A Global Forecast for Construction to 2030
[8] Nußholz J L K, Nygaard F, Whalen K and Plepys A 2020 Material reuse in buildings : Implications of a circular business model for sustainable value creation J. Clean. Prod. **245** 118546
[9] CEN 2021 Sustainability of construction works - Framework for assessment of buildings and civil

engineering works. EN 15643:2021.
[10] UNEP 2021 Catalysing science-based policy action on sustainable consumption and production: The value-chain approach & its application to food, construction and textiles
[11] UKGBC 2019 Circular economy guidance for construction clients: How to practically apply circular economy
[12] Iyer-Raniga U and Huovila P 2020 Global State of Play for Circular Built Environment. UN OPN SBC Programme
[13] Nußholz J L K, Nygaard Rasmussen F and Milios L 2019 Circular building materials: Carbon saving potential and the role of business model innovation and public policy Resour. Conserv. Recycl. **141** 308–16
[14] Verian K P, Whiting N M, Olek J, Jain J and Snyder M B 2013 Using Recycled Concrete as Aggregate in Concrete Pavements to Reduce Materials Cost Jt. Transp. Res. Progr. 17
[15] Moreno M, De los Rios C, Rowe Z and Charnley F 2016 A conceptual framework for circular design Sustain. **8**
[16] Ellen MacArthur Foundation 2016 Circularity in the built environment: A compilation of case studies from the CE100
[17] Ellen MacArthur Foundation 2017 Achieving 'Growth Within' Ellen McArthur Found. Achiev. "Growth Within"
[18] ING 2017 Circular construction Most opportunities for demolishers and wholesalers Circular construction involves the entire supply chain 2–13
[19] Mokhlesian S and Holmén M 2012 Business model changes and green construction processes Constr. Manag. Econ. **30** 761–75
[20] Huovila P and Boswell P 2018 Guidance Document on Procuring Sustainable Buildings
[21] Vatalis K I, Manoliadis O, Charalampides G, Platias S and Savvidis S 2013 Sustainability Components Affecting Decisions for Green Building Projects Procedia Econ. Financ. **5** 747–56
[22] Kats G H 2003 Green Building Costs and Financial Benefits Massachusetts Technol. Collab. 2–5
[23] WBCSD 2021 The Business Case for Circular Buildings: Exploring the Economic, Environmental and Social Value
[24] Schenkel M, Caniëls M C J, Krikke H and Van Der Laan E 2015 Understanding value creation in closed loop supply chains - Past findings and future directions J. Manuf. Syst. **37** 729–45
[25] Witjes S and Lozano R 2016 Towards a more Circular Economy: Proposing a framework linking sustainable public procurement and sustainable business models Resour. Conserv. Recycl. **112** 37–44
[26] Magdani N 2016 Design for deconstruction Nature **531** 446
[27] Klotz L, Horman M and Bodenschatz M 2007 A lean modeling protocol for evaluating green project delivery Lean Constr. J. **3** 1–18
[28] Hestin M, Faninger T and Milios L 2015 Increased EU Plastics Recycling Targets: Environmental, Economic and Social Impact Assessment 1–54
[29] Nick Banks, Preston I, Banks N, Hargreaves K, Kazmierczak A, Lucas K, Mayne R, Downing C and Street R 2014 Climate change and social justice: an evidence review 81
[30] Markkanen S and Anger-Kraavi A 2019 Social impacts of climate change mitigation policies and their implications for inequality Clim. Policy **19** 827–44
[31] Malhotra R, Behal M, Choudhary Y and Kaushik T 2021 Circular Built Environment Highlights from Asia. Policies, Case studies and UN2030 Agenda Indicators
[32] Penagos G, Morató J and Tollin N 2021 Circular Built Environment Highlights from Latin America and the Caribbean. Policies, Case studies and UN2030 Agenda Indicators
[33] Westerholm N 2020 State of Play for in Europe Circular Built Environment. UN OPN SBC Programme
[34] Lehmann S 2013 Low carbon construction systems using prefabricated engineered solid wood

panels for urban infill to significantly reduce greenhouse gas emissions Sustain. Cities Soc. **6** 57–67
[35] Osmani M, Glass J and Price A D F 2008 Architects' perspectives on construction waste reduction by design Waste Manag. **28** 1147–58
[36] PGIM 2021 Climate change investment approach has North American investors trailing the world: PGIM survey
[37] European Comission 2019 Communication from the commission to the European Parliament, the European Council, the Council, the European Econimic and Social Committee and the Committee of the Regions. The European Green Deal. (Brussels)
[38] Thelen D, van Acoleyen M, Huurman W, Thomaes T, van Brunschot C, Edgerton B and Kubbinga B 2018 Scaling the Circular Built Environment 36
[39] Wang K, Vanassche S, Ribeiro A, Peters M and Oseyran J 2017 Business models for building material circularity : learnings from frontrunner cases 315–8
[40] Loopfront 2022 Loopfront — Recycling and reuse made easy
[41] Cheong C, Kabore M, Arrabothu D, Badara Sy A and Asiimwe G 2021 Circular Built Environment Highlights from Africa. Policies, Case studies and UN2030 Agenda Indicators (GGGI and United Nations One Planet Sustainable Buildings and Construction Programme