Chapter 7
Circular Construction Platforms: A Systematic Literature Review

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Abstract Construction practices are critical for building our societies, but despite increasing focus on sustainability in the industry, the practices are inherently unsustainable – in absolute terms. The circular economy has been identified as a crucial paradigm shift to keep the construction within absolute boundaries of sustainability, covering waste and resources. The needed transformation comes with added complexity, uncertainty, and a requirement to innovate areas that historically have challenged the industry. This paper outlines preliminary research into the challenges of circular construction and how platform thinking can catalyze the sustainable transformation of construction toward circularity. The paper is based on initial findings from two systematic literature reviews of circularity and platform thinking in construction. The review identifies core circular economy challenges like (1) high variance, low volume, (2) short-term project-based optimization, (3) tough price competition, (4) industry fragmentation, and (5) lacking documentation of material flows and performance. Most of these challenges can be addressed by core features of platform thinking like (1) balancing and economy of scale, (2) long-term strategic thinking, (3) value and cost optimization, (4) value chain integration and coordination, and (5) documentation of platform architectures and performance. Thus, the paper finds platform thinking a promising strategy for enabling circular economy in construction, directly addressing SDG 12, and indirectly SDGs 8, 9, 11, and 13.

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7.1 Introduction and Purpose

The construction sector has been key in building our modern societies, and today's increasing population and urbanization create global demand for construction. Employing 18 M people and accounting for 9% of the European GDP (EC, 2016), the construction sector plays an important economic and societal role. However, the global industry's productivity rate has stagnated at a 1% growth rate per year over the past 20 years (Barbosa et al., 2017). Pushed by the covid pandemic, McKinsey foresees a transformation of construction "[…] from a highly complex, fragmented, and project-based industry to a more standardized, consolidated, and integrated one" (Bartlett et al., 2020). The 2018 World Urbanization Prospects report from the United Nations (2019) forecasts that 68% (2018, 55%) of the global population will be living in cities by 2050, with a daily expansion of the global urban area by 200,000 people. Metaphorically speaking, the demand for housing and other infrastructure accumulates every month to "another New York City" (Gates & Gates, 2019). Extrapolated to the demand of virgin raw material and emissions, the built environment accounts for 39% of greenhouse gas (GHG) emissions globally (UNEP, 2019) and consumes 40% of material resources; in the EU, the construction sector produces 30% of the waste (European Commission, 2019). Coupled with the forecasted increase in resource consumption, in absolute measures, current construction practices are unsustainable as these contribute to the exceedance of environmental boundaries and resource supply horizons.

The notion of circular economy (CE) is regarded as a promising and necessary solution to cope with future resource demands by aiming at closed material and energy loops (Geissdoerfer et al., 2017; EMF, 2013). Various circular solutions emerge in the construction industry. López Ruiz and colleagues (2020) identified waste management and the recirculation of recovered materials and their application of secondary building materials as promising solution pathways. The needed transformation comes with added complexity, uncertainty, and a requirement to innovate historically challenging the industry. In this context, several academic and industry reviews identify the importance and challenges of implementing CE in construction (e.g., Styles et al., 2018; Osobajo et al., 2020; Ottosen et al., 2021). Various initiatives have been initiated to address the circularity challenges and support the transformation of construction. Despite their potential to address the negative impacts, current practices and the application of circular strategies in the industry remain limited (González et al., 2021). The inherent complexity in the construction sector as a whole and the application of circular solutions specifically call for further actions. These challenges and opportunities related to value chain integration (Osobajo et al., 2020; Ottosen et al., 2021) and documentation (Styles et al., 2018) are currently not supported by systematic research and development activities. Platform thinking is a concept that has developed significantly over the past decade and has proven as a core strategy for handling the increasing complexities of value production. With inherent innovation capabilities and productivity gains (Jones et al., 2021), platforms provide a promising enabler to tackle various challenges of adopting fully circular construction practices and supporting the industry's productivity, leaving this paper with the opportunity of filling this gap.

Following this, the paper sets out to investigate and answer "how can platform thinking act as an enabler of circular economy in the construction industry?" The research applies a literature review to explore the intersections of the construction industry with both the circular economy and platform thinking. This constitutes the foundation for identifying relevant hypothesis of circular construction platforms (CCP). The paper ends by connecting the challenges of transforming toward a circular construction industry with platform thinking as a catalyst.

7.2 Methodology

This paper reviews existing literature within policymaking, industry, and academia. A systematic literature review extracts state-of-the-art knowledge from previous academic studies combined with central publications from industry and policymakers. The investigated topics concern circular economy, platform thinking, and the construction industry creating cross-sectional fields of studies as illustrated in Fig. 7.1.

The field of studies initially guided definitions of the search strings. The search strings were subsequently modified to include different terms of the same topics, ensuring a more fine-grained identification of relevant articles. Table 7.1 presents the reviewed search strings, including the number of papers reviewed.

A structured assessment of literature was conducted, undergoing four steps. The first step presented all papers generated from the search strings, followed by the

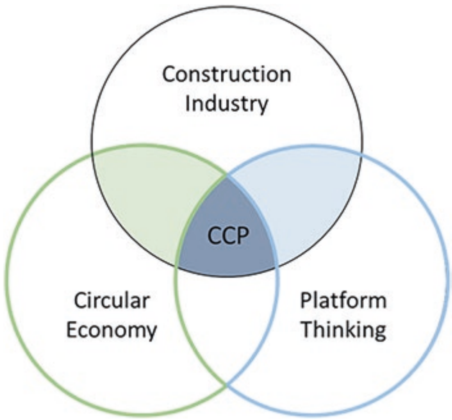

Fig. 7.1 The field of research investigating the integration of (1) the circular economy and (2) platform thinking within the construction industry to derive the intersection for circular construction platforms (CCP)

Table 7.1 Summary of the systematic literature review process and main steps, including the search strings, process, and number of reviewed papers

Search strings	Academic database	Total no. of papers	No. of papers extended	No. of papers screening of titles	No. of papers screening of abstracts
(“Circular economy” and “construction”)	Scopus	1.345	557	100	115
	Web of Science	790	386		
	Dimensions	1.052			
(“Circular economy” or “cradle to cradle”) and (“construction” or “construction industry” or “built environment”)	Scopus	1.489	643	200	
	Web of Science	874			
	Dimensions	584	239		
(“Product platform” and “construction”)	Scopus	86		86	87
	Web of Science	16			
	Dimensions	29			
((“Product platform*” or “mass customization” or “modular”) and (“construction” or “industrial housing” or “built environment”))	Scopus	18.344			
	Web of Science	6.111			
	Dimensions	885			

second step only including English-written papers and open access papers. The most relevant articles were selected based on headings in the third step. The final selection was made by reading the abstracts. Table 7.1 presents the process and number of papers.

7.3 Findings

In the following, we will present the preliminary findings from the literature review concerning circularity and platform thinking, identifying possibilities for developing a framework for circular platforms applicable to the construction industry.

7.3.1 Circularity in Construction the Construction Industry

To attain international goals of keeping resource consumption within certain planetary boundaries, there is a need to reduce the consumption footprint and double the circular material use rate (European Commission, 2020). A key challenge in the construction industry is that all construction and demolition wastes (CDW) derived from buildings' end-of-life stages are currently reused or recycled at a very low rate. Despite a low level of waste disposal sent to landfills, CDW's actual reuse or recycling in Denmark represents less than 36% of materials, where the major part (55%) is recovered and utilized in low-quality applications (MST, 2020). Hossain et al. (2020) likewise address the importance for CE in upgrading the quality of reused and recycled materials and components. An established consensus points toward circular solutions as the tool enabling the construction industry to perform a sustainable transformation (EU, 2020; Osobajo et al., 2020). Two essential topics are presented concerning circular solutions (Osobajo et al., 2020): waste management and resource reuse.

Taking the point of departure today, there are two dimensions describing waste management and resource reuse by either being proactive, enabling circular solutions for future constructions, or applying circular solutions addressing the current building stock. The common demand for both perspectives is data for decision-making. It is crucial to establish reliable CDW data and whereabouts of materials to support decision-makers and policies concerning CDW management and waste reduction in the construction industry (Styles et al., 2018; Hossain et al., 2020). Heinrich and Lang (2019) also address the importance of generating data for decision-making and suggest a forecast model of secondary raw materials acting as the foundation for recovery strategies and recovery mechanisms. A bottom-up approach taken by Lanau and Liu (2020) aims to map materials embedded in construction, such as buildings and roads. These approaches face one major challenge in ensuring and documenting the quality of materials, which act as a crucial parameter for reuse or recycling. Life cycle assessment (LCA) is a well-recognized tool for assessing sustainable potentials and consequences; however, the complexity of generating data is an obstacle to fully integrating this method in decision-making and comparisons to conventional solutions (Ipsen et al., 2021).

Styles et al. (2018) present comprehensive research resulting in 11 specific strategies, including proactive and reactive solutions aiming to reduce, reuse, and recycle CDW, such as designing waste and economic instruments creating economic incentives to use recycled materials. Five design strategies are presented by Ipsen et al. (2021), where Design for Disassembly (DfD) has achieved a lot of attention in the literature due to its simple logic of separating elements or materials and applying them in another construction setting. Styles et al. (2018) argue that DfD has the potential of designing out waste. Despite DfD's popularity, this solution is not unambiguous the correct solution. Critics indicate that a comparison based on a LCA considering DfD concrete elements and upcycled concrete elements does not put DfD in favor but rather proposes a combination of approaches. Furthermore, DfD does not directly produce solutions regarding resource scarcity and how to reuse or recycle the resources of today's buildings. It is well-defined that the construction industry requires circular solutions to accommodate the resource scarcity issue. In contrast, especially concrete has been of high priority for research due to the heavy carbon dioxide (CO_2) emissions (Styles et al., 2018; Gebremariam et al., 2020; Frederiksen & Madsen, 2016) and therefore included as an example of a circular resource.

Reusing concrete aggregates in new concrete elements further implies heavy transportation and processing while facing fierce cost competition against virgin materials to achieve commercial success (Styles et al., 2018; Gebremariam et al., 2020). Alternative solutions such as carving out concrete and applying them for other constructions can overcome the costly and CO_2 heavy transportation and processing, according to Frederiksen and Madsen (2016). However, neither of the mentioned solutions has experienced a commercial breakthrough, not caused by technological ability but rather economical and excess complexity of a reverse supply chain. An established consensus in literature addresses circular solutions' lack of competitiveness due to extended initial investment costs as one of the greatest barriers to adoption in construction (Ipsen et al., 2021; Orsini & Marrone, 2019; Hart et al., 2019). Furthermore, Hossain et al. (2020) present challenges of a reverse material flow where topics such as new business models, modified supply chains, and new processes are important. Aspects of missing policies and legislation, such as requirements for the quality of recovery and financial incentives, also act as barriers to integrating circular solutions when competing against regular solutions (Ipsen et al., 2021; Hart et al., 2019). However, a policy and legislation change can also accelerate market demand in the short and long term.

Sanchez and Haas (2018) take another perspective when addressing circular economy in construction. They argue that the lifecycle impacts of adaptive reuse of existing buildings are superior to new buildings. Furthermore, they present that current pre-project planning tools are insufficient for evaluation circularity. The research focuses on a framework for decision-making called Project Definition Rating Index (PDRI), developed by Construction Industry Institute (CII) and applied for several decades. Their research proposes four new parameters to evaluate the potential of existing buildings equally to new buildings. However, the project price is highly case-specific and can fluctuate, potentially even increasing the cost of new buildings (Table 7.2).

7.3.2 Platform Thinking in the Construction Industry

Platform thinking has developed significantly over the past decade and proven as a core strategy for handling the increasing complexities of value production, whether considering Meyer and Lehnerd's (1997) seminal work on product platforms or the rise of platform economies based on digital markets, such as with Airbnb (Parker et al., 2016). Platforms are generally described from either a technical or ecosystem perspective. The technical perspective (Baldwin & Woodard, 2009) views a platform as "a set of stable components that support variety and evolvability in a system by constraining the linkages among the other components" (p. 19). The ecosystem perspective focuses on the actors around the platform ecosystem, where Robertson and Ulrich (1998) define platforms as a collection of assets, such as components, processes, knowledge, people, and relationships all shared between several products. Platforms have proven successful strategies (Gawer, 2011) for achieving

Table 7.2 Summary of the challenges to the adoption of circularity in the construction industry

Challenges	Description	Author, year
1. High variance, low volume	Current construction practices focus on the realization of unique projects. This challenges the adoption of a circular economy since the material from demolitions is case-specific, resulting in high variance and low volume. This is detrimental to the recirculation rate and enforces low-quality application of secondary materials	Osobajo et al. (2020), Hossain et al. (2020), and MST (2020)
2. Short-term project-based optimizations	The traditional industry performance is challenged due to short-term success criteria with minimal long-term organizational learning. This hinders effective learning processes for systematically developing circular solutions that can be leveraged across projects	Styles et al. (2018)
3. Price competition	Cost represents one of the greatest drivers in current construction practices. Circular solutions experience excess and fluctuating costs compared to traditional solutions, e.g., initial investments. This impacts the demand because of lacking possibility of exploiting economy of scale to achieve cost reductions	Sanchez and Haas (2018), Styles et al. (2018), Gebremariam et al. (2020), and Frederiksen and Madsen (2016)
4. Industry fragmentation	The industry is highly fragmented and complex and lacks facilitation of continuity of assets, such as products or services, processes, or teams/people, enabling innovation and economy of repetition. Circular practices introduce new companies, processes, and solutions and thus add additional complexity and fragmentation	Hossain et al. (2020)
5. Lacking documentation of material flows and performance	Existing construction materials used for realizing unique projects are highly regulated and standardized. This challenges circular materials adoption as these lack data and documentation of "production" and formal quality levels	Styles et al. (2018), Ipsen et al. (2021), Heinrich and Lang (2019), and Hossain et al. (2020)

long-term strategic benefits in the automotive, aerospace, and defense industries. A key advantage of platforms is meeting market demands without requiring excessive resources (Robertson & Ulrich, 1998). By achieving high commonality and product adjustability, platforms can exploit economy of scale and still deliver variance in the form of differentiated products. A prerequisite for doing this is the ability to understand the architecture of platforms. Several frameworks exist to analyze and optimize a platform's ability to generate value. This includes Modular Function Deployment (Erixon, 1998), Product Family Master Plans (Harlou, 2006), and Product Variant Master (Hvam et al., 2008). Most of them include different perspectives, coordinating the customer's needs, product design, production processes, and resources.

Research concerning platform thinking in construction is limited (Thuesen & Hvam, 2011; Jones et al., 2021). Traditionally, the sector struggles to resolve the conflict between standardization to minimize cost and the variations in customer demands (Gibb, 2001), making platform thinking a valid candidate to consider when solving this challenge. Thuesen and Hvam (2011) present how a platform building on standardization, strategic partnerships, and continuous platform optimization enables a housing company to improve efficiency and solve the conflict between standardization and variation. By enabling the repetition of assets from project to project, the company's heightened experience, increased efficiency, and reduced costs while meeting the demanded value of the market. Furthermore, Thuesen and Hvam (2011) emphasize that the platform's success depends on initiating and maintaining long-term strategic partnerships between platform participants enabling continuous and structured innovation across the value chain.

Other case studies, including Wörösch et al. (2013) and Kudsk (2013a, b), document how product platforms can supply low-cost housing with a high level of customization. Platform strategies can be implemented from two levels: bottom-up through standardization of components/parts and top-down from building typologies. Wörösch et al. (2013) further suggest that standards and platforms promote the usage of drawings, photos, and prototypes in working descriptions rather than text, which improves communication and productivity. Other research has focused on less practical issues and more on the idea of using platforms in the AEC industry: Jansson et al. (2014) apply a redefinition of the definition of platforms by Robertson and Ulrich (1998), to adapt to the project-based and engineer to order context (ETO).

Today, construction's value and supply chain follow an institutionalized division of labor organized in short-term projects as the primary mode of production; this leads to a fragmented industry along three dimensions (Jones et al., 2021: 2). "Vertically, where different companies deliver different phases of a project (Alashwal & Fong, 2015), Horizontally, when different actors deliver complementary products and services (provided by specialists) at, approximately, the same stage of a process (Fellows & Liu, 2012); and longitudinally, where continuity of teams is disrupted by reassignment at the end of a project, taking any tacit, accumulated knowledge with them (Fergusson & Teicholz, 1996)." The fragmentation challenges the performance of the industry (McKinsey, 2020), driving specialization around institutionalized roles and archetypical business models (Berg et al., 2021) rather than organizing the value chain toward "building better buildings."

The organizational importance of platform thinking is also realized in Jones' et al. (2021) investigation of digital product platforms in UK construction firms. The well-defined product platform facilitates the development of capabilities and allows the integration of a fragmented industry. The horizontal integration captures specialized capabilities within the digital product platform and facilitates repetition across projects. Looking at the vertical integration, an essential finding is how the coordination between the design and manufacturing phase can be achieved by contracting instead of acquisitions while still managing to capture the tacit knowledge generated and exploiting the innovative bottom-up solutions (Table 7.3).

Table 7.3 Summary of enablers caused by platforms

Enablers	Description	Author, year
1. Balancing customization and economy of scale/repetition	Platforms enable customization with near mass production efficiency as it shares the theoretical underpinning with mass customization	Gibb (2001), Bonev et al. (2015), and Kudsk (2013a, b)
2. Long-term strategic thinking	Platforms enable long-term strategic development as it systematically looks for similarity across customers and avoids sub-optimization in projects	Thuesen and Hvam (2011) and Kudsk (2013a, b)
3. Value and cost optimization	Platforms enable systematic productivity development by separating the value production and cost reduction inspired by lean thinking	Robertson and Ulrich (1998) and Thuesen and Hvam (2011)
4. Value chain integration and coordination	Platforms enable integration and coordination of value chains through standardization, repetition, strategic partnerships, and structured innovation	Jones et al. (2021) and Thuesen and Hvam (2011)
5. Documentation of platform architectures and performance	Platforms enable transparency and comparability-based standardization and repetition among strategic partners. This is a central prerequisite to generating data from and assessing performance and consequences across products and processes	Thuesen and Hvam (2011), Harlou (2006), and Kudsk (2013a, b)

7.4 Discussion

7.4.1 Hypotheses of Circular Construction Platforms

Based on the preliminary results from the literature review, it should be apparent that platform thinking can address some of the core challenges of circular construction. Table 7.4 juxtaposes the identified challenges of CE with the enablers of platform thinking. We will in the following discuss how this translates into several hypotheses for circular construction platforms.

H1: Platforms enable variance of circular solutions and secondary materials The platform's ability to handle customizations while leveraging similarity across projects can address the current challenges of high variability and low volume of secondary materials. However, this will also challenge the current understanding of platform thinking that traditionally targets "end users" with variability. The concept of "end users" is problematic in a circular economy because there potentially is no end to using materials. Thus, platforms need to handle not only the variability toward construction but also the process of deconstructing buildings.

H2: Platforms enable the development of circular solutions that are relevant through time The current practices favor one-of-a-kind solutions that are contextualized to specific projects. While this customization strategy can potentially ensure the reuse of a small volume of secondary materials, the developed solutions would be subject to suboptimization that hinders long-term value delivery. On the

Table 7.4 Contrasting the challenges posed to the adoption of CE in construction with the enabling potential of platform thinking

Circularity challenges		Platform enablers
High variance, low volume	1	Balancing customization and economy of scale/repetition
Short-term project-based optimization	2	Long-term strategic thinking
Price competition	3	Value and cost optimization
Industry fragmentation	4	Value chain integration and coordination
Lacking documentation of material flows and performance	5	Documentation of platform architectures and performance
…		…

other hand, platforms enable long-term optimization that supports the basic principles of the circular economy.

H3: Platforms enable productivity development of circular solutions Current circular solutions are not competitive in the market, focusing on short-term costs at the expenses at long-term costs and value. The long-term perspective of platforms creates different incentive structures that separate and optimize value and cost, targeting the required productivity development for making secondary materials competitive. This can also be realized through increasing taxes and enforcing the role of politics and regulation.

H4: Platforms enable organizational specialization toward complex circular solutions The current fragmentation of the industry leads to lost knowledge from project to project, inefficient decision-making due to lack of knowledge and communication, and know-how remaining at the individual level (Jones et al., 2021). Platforms enable the pursuit of value-adding repetitions driving specialization in increasing complex circular solutions for certain markets and customers.

H5: Platforms enable detailed documentation of circular practices and solutions The current industry practices rely on general standards for documenting processes and products that are abstract, not always verifiable and comparable. This makes continuous improvement of the performance of circular solutions difficult, hampering wider diffusion in the industry. Platforms create shared standards for organizing products, processes, and organizations that are followed across projects. This makes the necessary infrastructure for monitoring the development of circular solutions.

7.4.2 Limitations and Further Research

Where the current construction value chain is thus not fit for purpose, handling the increasing complexity and uncertainty of the circular economy, the above-identified hypothesis documents the potential for introducing platform thinking as a catalyst for transforming construction toward circularity.

Today, there are only limited examples of leveraging platforms for sustainability – and even less so within the area of circularity. Minunno et al. (2018) and Mignacca et al. (2020) represent noteworthy exceptions targeting prefabrication and energy infrastructure, respectively. Thus, there is both industrial and academic potential for developing platforms that systematically improve the competitiveness of construction in general and of circular construction solutions in particular.

Platforms offer an organizational and technical order that allows specialization within a certain market and types of projects. Platforms create organizational learning and innovation infrastructures that allow for specialization and optimization across the supply and value chain. Moreover, it obstructs the development and implementation of circular practices requiring system-based long-term thinking, detailed understanding of the materials used, their assembly, and performance throughout the life cycle. This should be subject to further research and innovation in the industry.

While platforms represent a promising catalyst, they should not be seen as a silver bullet for handling all challenges of circular construction. Further research is also needed into the documentation of materials (Ottosen et al., 2021) and the broader shaping of markets through industry standardization and regulation (Ipsen et al., 2021; Hart et al., 2019).

7.5 Conclusion

CE takes two overall perspectives on the construction industry. Firstly, design solutions can enable future buildings to adopt circularity, and secondly, the potential of today's CDW as substitutes for primary resources. Combining the two perspectives into a reverse supply chain delivers processed or directly recycled CDW to manufacturers that act as suppliers of material or components for the construction industry. However, the literature indicates several barriers to withholding CE's integration in the construction industry. Platforms connecting relevant parties have proven effective in driving innovation and cost reduction and operating complex settings as established in construction. Thus, platform thinking holds the promise of overcoming the barriers identified to complete a sustainable transformation toward circularity.

This is important for the realization of the SDGs. For the global community to attain the international goal SDG 12 of keeping the resource consumption within certain planetary boundaries, there is a need to reduce the consumption footprint and double the circular material use rate (EU, 2020). The provision of sustainable cities and communities (SDG 11) is directly tied to the countries' ability to reduce their energy consumption and carbon emissions through circular construction practices. The application of circular construction platforms can directly address SDGs 12 and 11 and indirectly enable reduced climate change (SDG 13) and contribute to SDGs 8 and 9.

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