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The Case of the Building Construction Industry

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Design for Circularity: The Case of the Building Construction Industry

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Abstract. The role of design in transitioning towards a circular economy (CE) is strategic in the building construction industry as the potential for creating, developing, and sustaining circular value throughout the whole building life cycle is largely determined by the building design. Circular building design approaches that are being commonly deployed are often based on technical perspectives that assume buildings to be static products of the building construction industry. However, buildings are complex and dynamic with components and materials having their own individual life cycles, interacting dynamically with each other over space and time in a continual state of change. Moreover, changing stakeholder needs and expectations and other external factors add further layers of complexity in developing and sustaining the circular value created by the initial building design. Therefore, a holistic approach that accounts for the above contributors and integrates the building dynamism across its life cycle including stakeholder involvement, was ideated, based on the extant literature gap and the industrial need. The study conceptualised a holistic 'design for circularity' (DfC) framework based on a comprehensive literature review. The literature review was followed by 07 preliminary semi-structured interviews of relevant experts, so as to address relevant industry needs in developing this framework further. The findings enable the formulation of an overarching design centred framework to not only create, but also to develop and sustain circular value throughout the whole building life cycle, as presented in this paper.

Keywords. Building Construction Industry, Building Life Cycle, Circular Economy (CE), Circular Value, Design for Circularity

1. Introduction

The Circular economy (CE) can create economic, social, and environmental value in the building construction industry by advancing a systematic perspective over the whole life cycle of buildings based on new technologies and design approaches [1]. The critical role of design in transitioning towards a CE has been advocated by both academics and practitioners, since a major proportion of environmental impacts of products is determined by the design [2]. According to Beurskens et al. [3], a circular building is designed to facilitate disassembly and adaptability using sustainable materials to ensure and enable re-life options. However, a circular building is a one "that is designed, planned, built, operated, maintained, and deconstructed in a manner consistent with CE principles" [4, p.711]. Hence, designing for CE goes far more beyond than circular design as it should determine how the building is built, utilised, and ultimately handled during the end-of-life (EoL) stages [5]. In other words, this emphasises the need of transitioning from object-centric design to system-based design [2].

Hence, designing for CE should be viewed as an iterative process of critical decision making [6] that takes into account the stakeholder feedback [7], and integrates environmental, social, technical, economic, and temporal, organisational, cultural, and legal factors [8]. It is also pivotal to integrate all the stakeholders involved in different stages of a building life cycle to addressing CE targets in the construction industry [1]. Therefore, the present silo thinking in the building construction industry should be overcome and collaborative system thinking should be encouraged to not only create, but also to develop and sustain circular value throughout the whole building life cycle based on 'design for circularity'(DfC). Therefore, this study aims to develop and present a DfC framework for the building construction industry to create, develop and sustain circular value throughout the whole building life cycle.

2. Literature Review

In introducing the value chain concept, Porter [9] defined 'value' as the amount the customers are willing to pay for the goods or services offered by the organisation. This seminal definition of value is product-centered and customer-focused, which is one among many aspects of value. However, in the context of CE, value should be comprehended as a complex phenomenon, where it does not necessarily mean the economic value but also the non-economic components such as, environmental, social, and political value-addition of CE. Among the multitude of current definitions of CE, the study adopts one of the commonly used definitions of Ellen MacArthur Foundation [10, p.7], who characterised CE as *"an industrial system that is restorative and regenerative by intention and design"* that aims at keeping resources at their highest utility and value at all times. The definition emphasises the need of reconceptualising CE so as to achieve a zero or negative environmental impact level by design, over reducing the impact by EoL strategies such as closing loops with energy-from-waste or maximising resource recovery [11]. Van Stijn and Gruis [12] set forth 8 requirements that a circular design framework should entail:

1. A systems approach in which the buildings and their components are appraised within its wider system environment to circumvent probable rebound effects
2. An integral approach to ensure that the multiple disciplines in coherence within the design process
3. Inclusion of relevant circular design parameters
4. Provision of various practical design options under each design parameter
5. Relation to scale levels present in buildings acknowledging that each material and component has their own lifecycle while interacting within the building as a whole
6. Taking into account the longer lifespans of buildings
7. Inclusion of options that are built onto the unique features of the construction industry such as manufacturing techniques, materialisation, supply chain and financial arrangements
8. Accommodating different stages of a design process that is characterised by an exponential information growth curve

These requirements set the foundation for the integral components that a design framework should demonstrate. However, these requirements are meant for a design-tool focusing only on the design stage. It does not inform how circular value through design can be developed and sustained throughout the whole building life cycle. In other words, circular value emerges at the intersection of intrinsic properties (of materials and products) and relational properties (of building design and use), amidst the influence of several other multiple parameters [8]. Accordingly, Munaro et al. [13] assert that implementing CE in the building construction industry should undertake the fundamental strategies of:

- Monitoring and controlling material flows while evaluating the impacts of resources
- Designing taking into account the dynamism of the building during its life cycle
- Developing stakeholder relationships in the construction value chain to incentivise them to enable a CE in the building construction industry.

Therefore, CE transition in the construction value chain should be a system-based design approach, which is particularly designing a system for CE implementation that this study recognises as DfC.

Considering the above, the study identifies the elements that should be included in the proposed DfC framework in the construction industry, also leading to the following research methodology.

3. Research Methodology

A design-based systematic approach that encompasses not only circular value creation, but also developing and sustaining it, taking into account the building dynamism across its life cycle was ideated based on the extant literature gap and current and envisaged industrial needs. In order to identify the elements of the DfC framework, the study adopted a qualitative research methodology starting with a critical literature review. It was followed by 07 face-to-face semi-structured interviews conducted with CE experts in the construction industry, who had knowledge and experience in implementation of CE principles in circular design processes. Thereby, knowledge and experience of reducing, reusing, recovery and recycling materials including sustainable production and consumption, sustainable processes, waste management and resource efficiency were obtained to develop a better understanding of CE and the associated industry needs and priorities. Each interview lasted for about 45-60 minutes. Purposive sampling was used to select the interviewees based on the above criteria, as well as their availability and willingness to participate in the interviews [14]. Table 1 summarises the profile of experts who participated in the interviews.

Table 1. Profile of Expert Interviewees

Code	Location	Designation	Expertise	Type of Organisation	Key Experience (Years)	CE Related Experience (Years)
CI.1	Australia	University Lecturer	Architecture	University	>20	10-20
CI.2	South Africa	University Lecturer	Construction Management	University	10-20	5-10
CI.3	Hong Kong	Construction manager	Civil Engineering	Government	10-20	1-5
CI.4	Australia	University Lecturer	Construction Management	University	>20	1-5
CI.5	Hong Kong	Construction manager	Civil Engineering	Contractor	>20	>20
CI.6	Hong Kong	Construction manager	Construction Management	Contractor	>20	>20
CI.7	Australia	CE Researcher	Construction Management	University	10-20	10-20

The collected data were analysed manually using content analysis. Content analysis streamlines data categorisation by improving their contextual meaning [15]. The themes and codes were developed and assigned manually to reduces the volume of data that has to be handled and to enhance the focus on the data set rather than the process [16].

4. Research Findings

Based on the literature review and the findings from the expert interviews, the DfC framework was developed based on the Porter's generic value chain [9] and demonstrated in Figure 1. Porter [9, p.38] exclaims that value chain disaggregates an organisation into strategic activities, which serve as *"discrete building blocks of competitive advantage"*. Furthermore, the author establishes that value chain activities are inter-dependent and inter-related through linkages. These strategic activities create value and flows along the value chain coalescing the overall value; margin. Correspondingly, a circular building is envisaged as an organisation where the activities (elements) serve as 'discrete building blocks of circularity', and these inter-dependent and inter-related elements create circular value that flow though the chain to create the overall value of circularity.

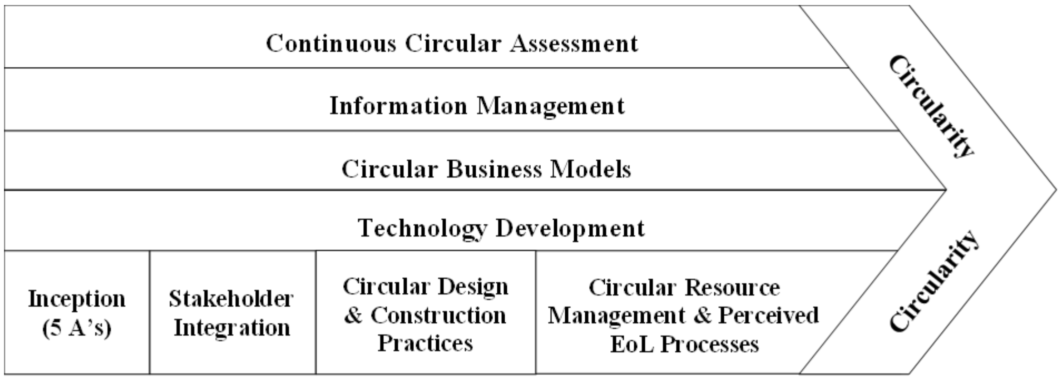

Figure 1. DfC Framework to develop and sustain circular value throughout the whole building life cycle based on [9]

As demonstrated, the DfC framework consists of eight generic value elements, which are discerned in terms of four core elements (inception - 5 A's (as in Table 2), stakeholder integration, circular design and construction practices, and circular resource management and perceived EoL processes) and four support elements (continuous circular assessment, information management, circular business models, and technology development). Based on the above notions, the study identifies the elements that should be included in the proposed DfC framework in the construction industry that in turn promotes system-based design over product-base design as in Table 2.

Table 2. Elements of DfC Framework

Elements of DfC Framework	Sources	
	Literature	Expert Interviewees
Core Elements		
Inception - 5 A's (Awareness, Attitude, Acceptance, Agreement and Apprehension)	17-22	CI.1, CI.2, CI.3, CI.4, CI.6, CI.7
Stakeholder Integration	5, 6, 18, 21- 29	CI.2, CI.3, CI.4, CI.6
Circular Design and Construction Practices	3, 6, 8, 12, 13, 23, 30-32	CI.3, CI.6, CI.7
Circular Resource Management and Perceived EoL Processes	23, 27, 32-34	CI.3, CI.4, CI.5, CI.6
Support Elements		
Continuous Circular Assessment	35	CI.2
Information Management	1, 6, 13, 25, 36-39	CI.2, CI.6
Circular Business Models	1, 7, 8, 13, 24, 32, 37, 40, 41	CI.2
Technology Development	26, 39, 42	CI.3

Hence, DfC is understood to be an endeavour to overcome both technical and non-technical barriers that hinder the pragmatic implementation of CE in the construction industry [2], wherein the people and continuity play a significant role not only in creating, but also in developing and sustaining circular value throughout the whole building life cycle, as discussed in detail in the sub-sections below.

4.1 Inception - 5A's (Awareness, Attitude, Acceptance, Agreement and Apprehension)
Stakeholder engagement and inclusiveness are critical in CE transition in the construction value chain. In this sense, all the stakeholders involved should be activated to transit towards a CE in the building construction industry. However, stakeholder behaviour and willingness to engage is unpredictable, hence requires a flexible approach [22]. These stakeholders may either be participants, who are having a financial interest or a non-financial interest in the project [5]. Ollár et al. [21] further argue that public should also be included as a stakeholder category when it comes to CE as they may have a non-financial interest in terms of environmental or social dimensions. Hence, the inception of DfC could

be characterised in terms of '5 A's'. Interviewee CI.2 emphasises that none of these would have triggered if it were not for the 'awareness' of stakeholders on CE concepts, specially, the clients, their 'attitude' and willingness to 'accept' reused or recycled materials in buildings. Most importantly, Interviewee CI.7 calls attention to the market pull in transitioning towards CE, where CE outputs are addressing the client needs. Accordingly, the stakeholders are required to be aware of the value-addition or benefits realised by transitioning towards CE in the building construction industry (Interviewee CI.4). Stakeholder engagement is also heavily dependent upon economic incentives to achieve CE (Interviewee CI.1). In addition, stakeholder engagement can be motivated via intrinsic motivation and regulatory incentives as well [20]. Furthermore, social constructs that hinder CE implementation must be overcome by raising awareness and educating stakeholders. Furthermore, given the persistent interpretative flexibility of CE concepts stakeholders, 'agreement' and knowledge & expertise ('apprehension') on the ontology and implementation of CE concepts are essential (Interviewee CI.3). As an example, misreading design for manufacture and assembly (DFMA) as identical to that of implementing CE strategies or that CE is entirely about construction waste management or recycling should be cleared at the outset to reach an agreement on circular project objectives.

4.2 Stakeholder integration

Even though CE research may feed technical innovations, value chain integration is fundamental in CE transition in the construction industry [26]. Interviewee CI.4 stressed that integration of value chain, bringing the involved stakeholders together remains a precondition to ascertain that circularity is developed and sustained throughout the building life cycle. Hence, DfC must enable long-term active involvement and interaction of the multidisciplinary stakeholders throughout the value chain [18]. Here, circular value is to perceive as a shared and co-created output for the betterment of the planet and its people in economic terms [41]. Furthermore, stakeholder collaboration is critical to address the complexity of building systems with different elements obsoleting at different times and relating to different stakeholders along the building life cycle [1]. Interviewee CI.4 reinforced the argument highlighting that the stakeholders of a building would not remain throughout the entire building lifecycle. Hence, it is vital that these stakeholders are somehow connected throughout, so that the created circularity is not lost. Restructuring the value chain might be required in integrating stakeholders such as introduction of new actors and creating new relationships between actors [1, 22]. Digital and online platforms such as building information modelling (BIM) can play a major role in actively engage and interact stakeholders [29], collaborate [1], share information [29], and manage resources and business models [26].

4.3 Circular Design and Construction Practices

A circular design process necessitates rethinking the design and construction practices to align with circularity taking into consideration the whole building life cycle. That means, the process should integrate resource efficiency strategies during early building life cycle stages [6], as well as EoL processes [23]. The use of recused or recycled materials instead of virgin materials encompasses resource efficient strategies during early building life cycle stages. On the other hand, incorporating design strategies, such as design for disassembly (DfD) [30], design for adaptability and design for flexibility [23] represents circular design strategies focusing the EoL processes. DfD encapsulates the recirculation of building materials [37], emission reduction [43] and waste reduction [32] as recoverable materials and components are intended to be returned to the material sourcing by the design. Offsite construction technologies are also recognised as a design strategy that can create circularity; however, circularity is not to be subsumed as modularity. A greater potential of creating circular value lies at the design and construction stages as they determine how the building is managed during its life cycle (Interviewee CI.3). Accordingly, the value proposition of construction contractors and the suppliers should also align with the CE agenda in order to ensure that the circular design is constructed adhering to CE principles (Interviewee CI.3).

4.4 Circular Resource Management and Perceived EoL Processes

Implementing CE principles requires stakeholders' knowledge and understanding of the perceived EoL of materials, products and components that may occur at different time frames of a building to facilitate re-looping the resources. Hence, different techniques such as '3R' principles (reduction, recycling, and reuse) can be applied at different life cycle stages of a building to facilitate resource recovery. Even though 3R principles are usually recognised as waste management strategies [30], they can be applied in the context of the CE as well. Hence, it is to be understood that waste management is not analogous to CE, and that it is one of the techniques to be applied within the CE domain [29]. However, the application of these strategies must be carefully planned based on their value-addition in the DfC framework. Reverse logistics facilitates closing the loop criteria [34], facilitating the maximum recovery of salvaged waste. Urban mining of the built environment facilitates visualisation and mapping of materials, products and components stocked in the built environment within a specific spatial area [38]. Furthermore, selective deconstruction is to be applied over conventional demolition as it improves the construction and demolition waste from landfilling [19]. For example, Australia has a well-established recycling and waste management industry (Interviewee CI.4) while Hong Kong is lagging behind. Public landfilling in Hong Kong is therefore convenient and cheaper, discouraging the stakeholders to implement CE strategies at the perceived EoL stages (Interviewees CI.5 & CI.6). Hence, established systems to collect, process and re-loop resources at the perceived EoL of materials, products and components are necessary to enable the transition towards a CE in the construction industry (Interviewees CI.4 & CI.5). This also emphasises the need of a centralised system, such as BIM to track and manage the resource changes occurring throughout the building life cycle and how these materials are re-looped into the economy, which in turn highlights the need of stakeholder integration across the building life cycle.

4.5 Continuous Circular assessment

In line with a famous statement attributed to management guru Peter Drucker: "*you can't manage what you can't measure"*, CE transition must be supplemented with circular assessment systems to facilitate informed decision making [44]. Accordingly, circularity indicators that may either be qualitative or quantitative, encapsulating social, cultural, environmental, and economic dimensions [40] can be employed at either macro, meso or micro levels to determine the circularity potential of systems. The archetypal circular assessment methods are life cycle assessment (LCA) and material flow analysis (MFA). Interviewee CI.2 proposed that these assessment methods should entail a life cycle perspective to discern the option that yields the highest circular value in the building life cycle. However, the need for assessing the circularity throughout the building life cycle so as to ascertain that it is developed and sustained, is inadequately addressed in the literature, apart from the lack of standardised and commonly agreed circularity indicators. Hence, it is proposed that systematic circularity performance measurement systems should be developed so that circularity can be assessed throughout the building life cycle based on multi-dimensional parameters.

4.6 Information management

While the most influential decisions are made by the construction clients; investors and users, decision making of different actors occur at different points of the construction value chain, significantly affecting each other due to the complex interactions between them. Therefore, a well-developed communication system [29] and co-ordination among actors throughout the building life cycle promotes stakeholder integration. Given the longer life span of buildings, information management is critical to ensure the traceability of information [33] and transparency of information exchanging [29]. It determines the commercial viability of businesses and hence verification of the integrity and composition of building is essential, which can potentially be realised via a digital system [25]. BIM is a promising technology that not only provides progressive definition of building elements but also facilitates integration of stakeholders across the building life cycle (Interviewee CI.6). Also, material passports (MPs) have been proposed as a tool to record and trace the circularity potential of materials, products, and components throughout the building life cycle [1]. Regardless of tools and techniques to be utilised in information management, Interviewee CI.2 encouraged information driven decision-making including change management to ensure that the circular value is developed and sustained throughout the building life cycle.

4.7 Circular Business Models

Circular business models incorporate a collection of circular value propositions and inter-relationships between stakeholders and can influence the entire construction value chain [45]. Hence, transitioning to a CE essentially requires innovative business models to bring about engagement, inclusiveness, and the integration of the stakeholders in the value chain. Circular contract models based on product service systems (PSS), such as leasing, take-back after use, buy-back after use can provide attractive circular value proposition to stakeholders [12]. Circular procurement models, specially implemented by the public sector provides stimulation and encouragement to the construction industry transition to a CE in the construction industry [24]. Furthermore, transition to a CE demands changes in the ownership models as leaving the ownership with the customer may pose uncertainties in sustaining the developed circular value [7]. Accordingly, the current business models must be redeveloped to incorporate circularity in their value proposition (Interviewee CI.2). Furthermore, government can overhaul their procurement systems, e.g., with incentives, to help develop a business case for CE and to accelerate the CE transition.

4.8 Technology Development

Technological innovation is a central aspect in transitioning towards a CE in the construction industry. Macro level technological innovations in industrial symbiosis (IS) such as application of galvanised sheet metal scrap in metal facade systems of building exteriors [46] or agricultural products such as rice straw or sugarcane bagasse in producing construction materials. Materials, components, and products level innovations include recycled concrete [29], circular building infills [7], recyclable roof felt and reusable window frames [18], circular Kitchen modules [12] and so on. However, Interviewee CI.3 emphasised the importance of research and development in materials and technologies beyond research level to implementation level, so that the stakeholders have a range of options to decide on, when implementing CE principles.

5. Discussion

Dokter et al. [2] claim that a predominant percentage of environmental impacts are ordained by its design, accentuating the critical role of design in CE transition. However, mere shifts in production patterns (through design) with no changes in the consumption patterns are considered resource efficient practices of improving existing conditions rather than CE transitions affirming radical changes in resource productivity and use [11]. Hence, design-based frameworks that enable CE transitioning, while creating, developing, and sustaining circular value throughout the whole building life cycle are critical. Porter's generic value chain [9] has been adopted and/or adapted in a variety of value-related fields such as Knowledge Management in order to decipher and then depict the interplay of strategic activities related to value-addition. Perceiving CE transition through the theoretical lens of value, the study presents a Porter-like framework of DfC, taking into consideration a circular building throughout its life cycle constituting of the construction value chain as the unit of analysis (an organisation in case of Porter's value chain). Similar to Porter's generic value chain [9], the elements have complex relationships with each other and also with the externalities. For example, existence of an established resource recovery industry in a specific context facilitates uncomplicated perceived EoL processes, while such existence also exhibits the stakeholders' awareness and apprehension of the basic CE principles. The framework also emphasises the need for centralised systems to create, develop, and sustain circularity. For example, BIM not only helps create circularity during the design stage, forecasting the EoL stages [37], but also integrates the stakeholders, facilitates information, and change management and continuous circularity assessment. The framework may also need introduction of new players to the value chain such as a 'Material and Component Bank' to manage the transfer of materials and components extracted from deconstructed structures to a new structure as proposed by Cai and Waldmann [30].

6. Conclusions and Further Research

The paper presents the findings of an on-going research on 'design for circularity' (DfC) that amplifies the need of shifting from object-centric designing to a more system-based design underpinning the need of systematic perspective of CE transition. Therefore, the study developed a DfC framework based on Porter's generic value chain notion [9] to enable CE transitioning, while creating, developing, and sustaining circular value throughout the whole building life cycle. The core elements of the framework are Inception - 5 A's, stakeholder integration, circular design and construction practices, and circular resource management and perceived EoL processes, while continuous circular assessment, information management, circular business models, and technology development support the core elements in this transition. Although the framework has not yet been validated using rigorous scientific methods, it alerts academia to the need for comprehending CE transition in the building construction industry as a systematic endeavour rather than point-based innovations. Practitioners can use the framework to identify potential improvements in implementing CE principles in their projects. Policy makers can also make use of the framework to develop strategies that can vastly facilitate the supporting infrastructure in CE transition in the building construction industry. Even though political, economic, legal, social externalities could significantly affect this transition, these are not taken into account in the current framework development. Hence, the framework can be further developed considering these externalities and their influence on CE transition. Furthermore, the complex inter-relationships emerging from the sub-levels of these elements are worth studying to tackle the dynamic effects that affect the CE transition in the building construction industry.

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