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Implementing circularity in the construction process: a case study examining the reorganization of multi-actor environment and the decision-making process

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ABSTRACT

Circularity aims to make waste obsolete by both closing and narrowing resource loops and by extending the lifespan of materials and products. This fundamentally different approach to construction practices necessitates a completely different method of organising the construction process. The rounds of decision-making undertaken by different actors at particular moments in the construction process have a significant role to play in this regard. Consequently, this research aims to analyse current circular practices for both the multi-actor environment and the decision-making process. An analytical framework is developed based on the theoretically-informed assumption that actors are responsible for decision-making and that circular strategies are an effective means through which to integrate circularity within the construction process. This analytical framework is applied to three circular building cases in the Netherlands, by drawing upon stakeholder interviews and documentation. It can be concluded that: some conventional actors have acquired knowledge on circularity; and that there is an emergent group of expert actors specialising in circularity. Both types of actors are a prerequisite for implementing circular strategies at both the beginning and end-of-life phase of a building; and should be involved early on to influence decision-making on circularity, especially concerning the long-lived layers of a building.

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Introduction

The building sector and attendant linear construction process account for a large share of total global waste production and CO_2 emissions. Ridder (2018) posits that the building sector generates around 45% of the total waste in the Netherlands, while only contributing to 10% of the country's GNP. These figures testify to the importance of reducing waste and dealing responsibly with materials and resources. In contradistinction to a linear construction process, a circular construction process helps to cut down on production and consumption rates (Mulhall and Braungart 2010). By virtue of closing material cycles, this approach aims to handle resources more consciously by means of prevention, reusing, recycling and decomposition, in conjunction with utilizing waste (that is generated after demolition) as a resource (McDonough and Braungart 2009, Geissdoerfer *et al*. 2017).

While circularity appears to have substantial promise, specific difficulties arise during its implementation. Adams *et al*. (2017) delineate several barriers that are inherent to the conventional way of organizing the construction process, including, amongst other things: a lack of awareness and knowledge of the circular construction processes that designers and clients have; a fragmented supply chain; and lack of consideration and incentives at both the start and end phase of a building's lifespan (Adams *et al*. 2017). Moreover, Gorgolewski and Ergun (2013) purport that other actors should probably be involved in this process, such as demolition or salvage companies that can aid the sourcing of reused materials. In conjunction with this, Hart *et al*. (2019) state that there needs to be a marked shift in stakeholders' behaviours and attitudes, in order to further develop the circular economy in practice.

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This research aims to analyze current circular practices and to provide recommendations for the multi-actor environment and decision-making process, to facilitate the implementation of circularity in the construction process. It is assumed that the impact of circularity is maximized when circular strategies are considered from the very beginning of the construction process. Based on this assumption, the paper sets out to address the following research question: "Which actors should be involved in the design-making process to ensure circular use of materials and resources across all phases of the construction process?"

This paper is divided into six sections. After the introduction, theories on actors and decision-making moments in the construction process, on how best to integrate circularity into the construction process by means of circular strategies, and on the barriers and drivers of a circular construction process, will be discussed in turn. Section three introduces the methodological approach, including the analytical framework, data collection and analysis, and case study research. This is followed by the results section, which presents the results from the case study research. The next section discusses the findings and situates them within extant research in the field. Finally, the paper concludes by highlighting the most important conclusions and providing avenues for future research.

Theory

Construction process: multi-actor environment and decision-making moments

The analysis of the cases examined in this study clearly links to literature on actor analysis, network analysis and decision-making processes. Within the context of the construction industry, the construction of a building is ordinarily executed by a project team. For the purposes of this paper, such teams can be regarded as both a temporary and interfirm multi-actor environment, in which actors are interdependent and dependent on each other in order to impose desired solutions (in these cases for the client). This is generally hampered by different interests and different levels of influence these actors have (Enserink *et al.* 2010). These actors, part of the project team, typically exert a formal influence over the decision-making process, engaging in intense collaboration and frequent communication. As well as the project team members, this dynamic network of actors also encompasses other relevant stakeholders, who are indirectly involved (Aminoff *et al.* 2016). While these actors are not part of the project team – their primary role is to provide advice – they nevertheless can contribute to decision-making, albeit from a less influential position (informally) and on a much more infrequent basis. Alongside those actors traditionally involved in the construction process, such as contractors and designers, research has also highlighted the benefit of involving actors with knowledge of circularity to enhance and accelerate implementation (Osmani *et al.* 2006). These kinds of actors perform the following roles: a circularity expert (usually a consultant or advisor); a dealer in salvaged goods (able to identify and market valuable secondary construction components); a reclamation expert (has knowledge of where and how to reclaim materials); and a dismantler (Addis 2006, Gorgolewski 2008, Adams *et al.* 2017).

All these aforesaid actors contribute to the implementation of circular ambitions and strategies through applying and sharing their knowledge. Given that substantive experiences in the field of circularity are limited, the project team must explicitly identify and integrate actors' knowledge. This requires the actors in the project team to make collaborative decisions that are concordant with their circular ambitions, and be open towards new insights, technologies, and innovative approaches. To stimulate the transition towards a collaborative and innovative approach, specific actors in the project network must be granted, or assume for themselves, the power to be the driving force behind this new approach.

Actor analysis, rooted in stakeholder analysis, and network analysis provide methods and concepts through which to study the multi-actor environment in the construction industry. Although the method of actor analysis originates from policy problems and processes, it has also been proven to be valuable for project management and design-related activities (Mitroff 1983, Freeman 1984, MacArthur 1997, Scholes 1998). Actor analysis can contribute towards a deeper understanding of the multi-actor environment in construction processes, giving insight into the relations between actors and their influence in the decision-making process.

Enserink *et al.* (2010) posit that an actor analysis comprises the following key concepts: actors, resources, relations, positions, and influence. An actor is defined as "a social entity, person or organization, able to act on or exert influence on a decision" (Enserink *et al.* 2010, p. 80). With respect to this study, an actor can either be involved formally as a member of the project team – a position that is formalized in a contract – or informally as an advisor or consultant.There are specific relations at play between the various actors that serve to illustrate the different connections between actors, as well as indicating the exchange of information or coordination between actors (Ruijven *et al.* 2015). Relations are formed by both the duration and frequency of communication (Ruijven *et al.* 2015). Ultimately, it is both the positions of the actors and the interactions between them that constitute the multi-actor environment. The positions of actors can be determined in relation to their centrality in the network, based on the number of ties between certain actors in relation to the maximum number of ties (Ruijven *et al.* 2015). With respect to the frequency of communication, therefore, the actor with the highest number of relations and highest number of relations that display frequent communication is positioned centrally in the network. Within network analysis, centrality indicates the importance of a certain node in the network. The degree of centrality is often interpreted as the power that an actor has to influence decision-making by being able to facilitate and steer communication between actors (Borgatti *et al*. 2009). On this basis, we state that a higher amount of communication, therefore, relates to a large degree of influence in decision-making. An actor's influence over decision-making is depicted by the size of the node. Influence over decision-making is determined by actors' involvement in decision rounds and actors' abilities to steer and impact decision-making by their resources, such as certain information, knowledge, or formal power that actors possess (Enserink *et al*. 2010).

Both the actual dynamics of these interactions and the ways in which involvement and influence *evolve over time* can be ascertained by unravelling the decision-making processes. The work of Teisman (2000) discusses models that are expedient for unravelling complex decision-making processes. The relevance of such models, especially the rounds model, for the present study pertains to their ability to identify decision-making processes over time, including the involvement and roles of multiple actors and their influence over decision-making (Teisman 2000). The rounds model combines two aspects that are inherent to decision-making: a combination of interdepending actors offering different views on solutions for the concerned problems; and progress in decision-making in terms of implementing solutions (in this study towards constructing a circular building) is made through interaction (Teisman 2000). Klijn and Koppenjan (2016) further enhanced researchers' ability to visualize the decision-making process by means of the identification of rounds. A round designates a specific moment in time when the most crucial decision(s) on a topic is/are being made. This is predicated on the concept that prior to making a decision, various consultations and discussions take place, during which certain actors are involved and collaborate with one another. Hence, this process of discussion and collaboration prior to a decision being made is defined as a round. A construction process can thus be said to consist of multiple rounds that take place either sequentially or in parallel. The rounds that include decision-making on circular strategies (CSs) are of particular interest in this study and are discussed below.

Integrating circularity into the construction process: circular strategies

A circular building approach can be defined as "a life cycle approach that optimizes the buildings' useful lifetime, integrating the end-of-life phase in the design and uses new ownership models where materials are only temporarily stored in the building that acts as a material bank" (Leising *et al*. 2018, p. 977). As Pomponi and Moncaster (2017) also note, a circular building approach should take into account the complete life cycle of the building. The conventional end-of-life phase (which in this paper is framed as "post-phase"), which results in waste, should therefore be reconsidered and replaced by reduction, reuse or recycling (Stahel 2016, Geissdoerfer *et al*. 2017). Preparations to guarantee dismantling, reuse, or recycling at the end of life could, and should, already be made in the design-making process (initiation, preparation and design phase). In this paper, these early phases of the construction process are referred to as the "pre-phase".

Several authors have argued that CSs guarantee reduction, reuse, and recycling. In relation to materials and resources, some CSs are focussed on dealing with end-of-life waste, while others are focussed on preventing waste from the outset (Addis 2006). Although authors typically use different words and slightly different categorizations, there appears to be a consensus that "reduction" (including prevention & reduction) is the main means through which to deal with waste, followed by "reuse" (including repair & maintenance, reuse & redistribution, and refurbishment & remanufacturing), and "recycling" (including recycling, cascading & repurposing, and organic feedstock) (Bocken *et al*. 2014, Lüdeke-Freund *et al*. 2018, Ritala *et al*. 2018, Joensuu *et al*. 2020). The following CSs were identified through recourse to Lüdeke-Freund *et al*.'s (2018) framework: (1) maximizing material and energy efficiency and dematerialization; (2) functionality without ownership/product-service system (PSS) and extending product value; and (3) extending resource value and industrial symbiosis, see Table 1.

The CSs (1) maximizing material and energy efficiency and de-materialization both focus on preventing waste from the outset. Value is created by reducing components and material input and output (Ritala *et al*. 2018). This results in using fewer materials and resources, thereby narrowing the resource loops. In concrete terms, this can be applied by means of evaluating the need for a (new) building, using fewer materials, using lightweight materials, and using efficient construction and manufacturing processes (Lüdeke-Freund *et al*. 2018).

Aiming to reuse simply slows the resource loop down, since the lifespan is extended (Ness and Xing 2017). The accompanying CS (2) extending product value can be implemented by means of maintenance, reparation, or redistribution (Kibert 2013, Ritala *et al*. 2018). The CS (2) functionality without ownership, which is also known as a PSS, aims to provide a service instead of a physical product or component (Tukker 2015, Ritala *et al*. 2018). This strategy is based on the assumption that a product-oriented business is likely to increase the number of products they sell, and thereby the materials they use, whereas a service-oriented business' primary motivation is to extend the product's lifespan and minimize maintenance (Tukker 2015).

The aim to recycle requires the processing of components into materials and subsequently into new components (Iacovidou and Purnell 2016). Given that recycling often requires energy, this option cannot be considered to be truly circular, especially since the value is lost when components degrade in function (downcycling) (Bocken *et al*. 2014, Adams *et al*. 2017, Lüdeke-Freund *et al*. 2018). According to McDonough and Braungart (2009), for biological nutrients, the resource loop can be closed through the means of decomposition. Therefore, biological and technical nutrients should be separated (McDonough and Braungart 2009). The CSs (3) extending resource value and industrial symbiosis both focus on aligning the waste output from one industry as a valuable resource for another (Lüdeke-Freund *et al*. 2018, Ritala *et al*. 2018). In line with the above discussion, while CSs predominantly aim to instantiate changes in the "end-phase" of construction, one could argue that the pre-phase of construction management is more decisive in determining the successful implementation of CSs (Johansen and Wilson 2006, Kibert 2013).

Table 1. Framework of circular strategies (CSs) and aims, patterns, design strategies, resource strategies, and value strategies, which can be applied at both the pre- and post-phase of a building's lifespan, based on and expanded from Addis (2006), Bocken *et al*. (2016), Lüdeke-Freund *et al*. (2018), and Ritala *et al*. (2018).

Circular strategy (CS):	(1) Maximize material and energy efficiency, de-materialization	(2) Functionality without ownership/product service system (PSS), extending product value			(3) Extending resource value, industrial symbiosis		
Aim	Reduce		Reuse			Recycle	
Pattern	Prevention & reduction	Repair & maintenance	Reuse & redistribution	Refurbishment & remanufacturing	Recycling	Cascading & repurposing	Organic feedstock
Design strategy	Resource efficiency		Long-life, life extension		Life extension, technical & biological cycles	Technical & biological cycles	Biological cycles
Resource strategy	Narrowing		Slowing down			Closing	
Value strategy	Reduce component & material input & output		Retain component value			Retain material value	

Applying these strategies to buildings highlights differences in the applicability for both long-lived layers (site, structure, skin) and short-lived layers (services, space plan, stuff) (Brand 1994). This is based on the concept that a building comprises several layers, all of which include different components and materials, and each layer should be organized in such a way that ensures they are maintained at the same level of frequency and share the same lifespan (Brand 1994). According to Ridder (2018), long-lived layers that have a lifespan that generally transcends that of the building itself should be reused. Conversely, short-lived layers, whose lifespan is shorter than that of the building, should be recycled with a minimal amount of energy (Pomponi and Moncaster 2017, Ridder 2018). For short-lived layers, "suppliers can take responsibility […] via take back schemes", or via the means of leasing or buyback guarantees (Leising *et al*. 2018, p. 984). Components and materials with a long life cycle can be reused, which would be facilitated by a marketplace (Leising *et al*. 2018).

Consequences of a circular construction process: drivers and barriers

The description of the current construction process, as well as the various actors who are responsible for decision-making and the aforesaid potential circular strategies, testify to the need to organize the construction process and its supply chain differently, in such a way that engenders a transition towards a circular built environment. A number of scholars have already identified several enablers and barriers within the construction process that either accelerate or delay circularity within building projects (Adams *et al*. 2017, Galvão *et al*. 2018, Hart *et al*. 2019, Tura *et al*. 2019). Although barriers have been detected in a variety of domains, including the environmental, economic, social, institutional, technological, and informational domains, a lack of collaboration in the supply chain and organizational factors within the process management of projects itself have both been found to hamper the transition towards circularity (Hart *et al*. 2019, Tura *et al*. 2019). The complexity of the industry as a whole, which is reflected in the wide variety of different actors involved in the construction process, is not conducive to the swift implementation of circular strategies. However, as aforesaid, the various decision-making rounds that different actors engage in at specific moments in the construction process do play a critical role. Whether or not these different decision-making rounds and additional actors with specific knowledge are required within a *circular* construction process is the key question driving the present research.

Methods

Analytical framework and data analysis

For the purposes of the case study research, we adopted an analytical framework that was grounded in theoretical insights on three topics: actor analysis in combination with network analysis; decision-making processes; and circular strategies. The case studies were analyzed in accordance with a qualitative research method that is expedient for identifying detailed information on current industry practices related to these aforesaid topics. Data was gathered with respect to (1) those actors responsible for and involved in decision-making; (2) decision-making rounds; (3) implementation of CSs. The results of the data analysis of the actor analysis in combination with the network analysis and decision-making process were visualized for each case. Figure 1 shows how this analysis was represented.

The results pertaining to those actors responsible for decision-making were primarily retrieved via visualization of the multi-actor environment for each case. The composition of the network provides a representation of the actors as nodes, positions, relations or ties, and influence over the decision-making of those actors involved in the circular construction processes. Actor analysis, based on the method of stakeholder analysis, in combination with network analysis is applied to visualize and reflect on the multi-actor environment of each case. The representation of the multi-actor environment is based on a six-step approach adopted from Enserink *et al*. (2010), including:

1. indication of the problem as a point of departure;
2. inventory of actors involved;
3. identification of formal roles and resources;
4. determining interdependencies, that is, relations and frequency of interaction;
5. determining position within the network;
6. determining influence in the network.

In the selected cases the problem as a point of departure for these projects does concern a circularity-related ambition from the client that needs to be adopted and implemented by the actors by means of a design and construction process. Table 2 displays how the data gathered from the interviews provided information into the composition and visualization of

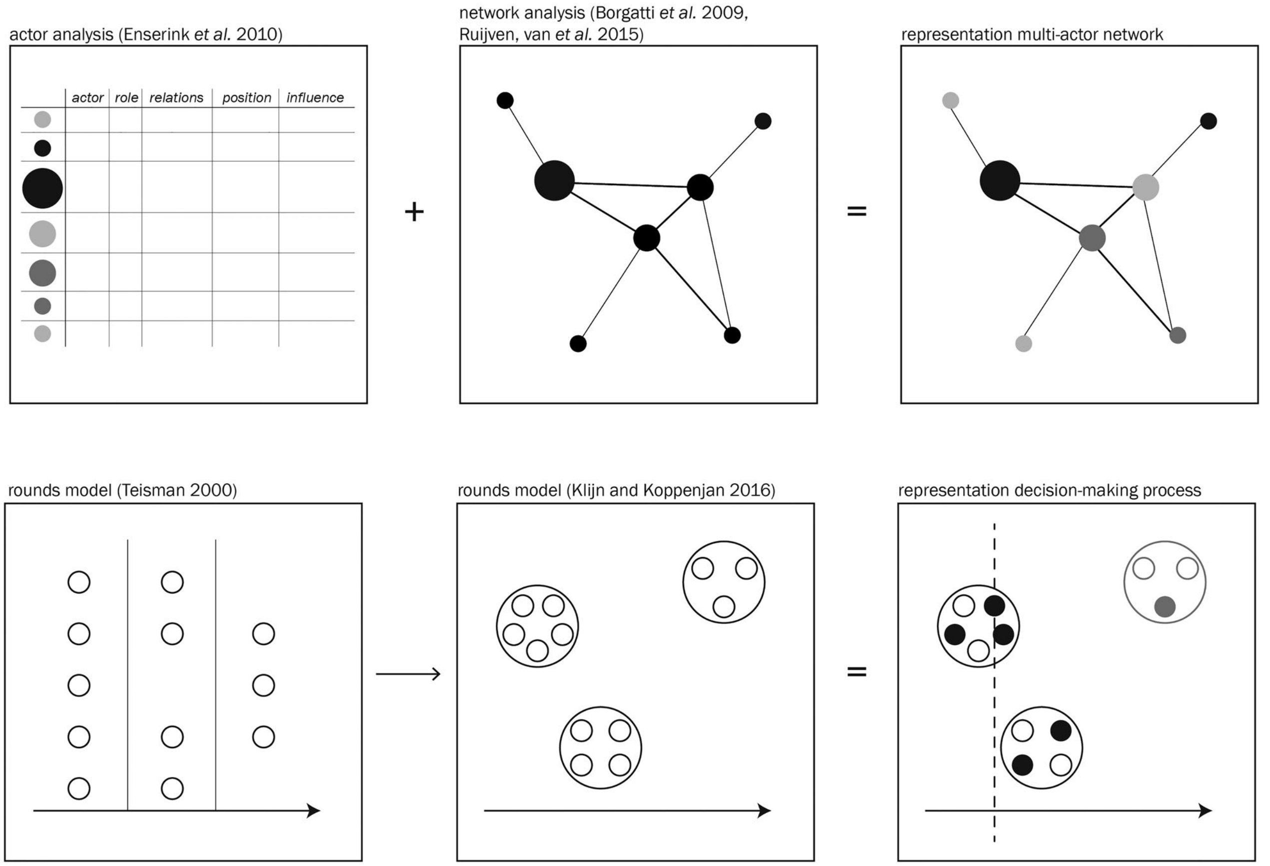

Figure 1. Adopted theories for representation of the multi-actor network and decision-making process.

Table 2. Data analysis: coding of interview data for the multi-actor environment visualization.

Concepts multi-actor environment	Visualization		Retrieved interview data
Actor	Node	Black dot	Social entity, person or organization formally or informally involved in project
Relation/tie	Connection to other actors displayed by a line	- Thick line - Thin line	- Relation displaying weekly two-way interaction - Relation displaying biweekly two-way interaction
Position	Position within the network based on centrality	Distance to centre	Actor with highest number of relations and highest number of relations that display frequent communication is positioned in the centre, other actors are positioned consecutively
Influence	Size of node	- Large - Middle - Small	- Substantial influence, involved in 5 rounds - Moderate influence, involved in 2-4 rounds - Little influence, involved in 1 round

the multi-actor environment. It is important to bear in mind that this representation is a static depiction of actors' interactions, based on a sum of several interactions. Relations, in the work of Ruijven *et al*. (2015) also depicted as ties, that are visualized in the diagrams do not depict all relations, but merely those that are most important for the problem as a point of departure (Enserink *et al*. 2010). This also holds for the actors. The inventory of actors is not exclusive, but are those determined to be most important in line with the problem as a point of departure and context of the project. Enserink *et al*. (2010) specify that experience indicates that a useful actor analysis should include between ten and twenty actors.

The visualization of the decision-making process is reliant upon theory on unravelling complex decision-making processes (Teisman 2000, Klijn and Koppenjan 2016). This includes the following elements: actors, rounds, the timing of decisions, and implementation of decisions. Table 3 displays how the interview data was translated into a visualization of the decision-making process. From the interviews, the following was retrieved:

1. what decisions were made in relation to CSs resulting in the identification of certain rounds;
2. who were involved in these rounds? This was specified into *involvement* measured by consulting and providing advice or *influence* on decision-making measured in terms of participation in decision-making rounds and steering or deciding towards certain solutions (i.e. CSs);
3. when decisions were made, thus in what phase of the construction process the rounds can be positioned;
4. whether the decision on a certain CSs was also implemented and applied into the building project.

Rounds are depicted by circles and positioned on the x-axis. A round relates to a decision regarding a circular strategy (or subsequent pattern or design strategy). As one can discern from Table 1, three main circular strategies were identified. The interview data were used to identify CSs relating to decision-making rounds. Time, on the *x*-axis, is divided into periods in accordance with construction process phases: initiation, preparation, design, build, financing, maintenance, and operational phase. The different phases of the design-making process (pre-phase) are demarcated by a vertical dashed line. By identifying *when* decisions were made, it can thus be evaluated whether decisions were made early on and whether there is a relation between decisions made early on and their subsequent implementation. It must be noted that *how* decisions were made was not part of this study. The decision-making process typically changes course multiple times (Teisman 2000). The relations between different rounds and the concept of shifting content during the construction process were not investigated.

Data collection

Information for the actor analysis and network analysis and analysis of the decision-making processes is gathered through two types of sources: text analysis and semi-structured interviews with key informants. Text analysis includes analysis of secondary data, which are: project documents, policies, (architectural) plans, and meeting notes. These sources provide information to establish an inventory of involved actors, their roles and resources; and information about the outcome of the construction process (the building itself and its materials) and the actual implementation in practice. As also stated by Enserink *et al.* (2010), in order to assess the influence and involvement of actors in the network and within the decision-making process, interviews with key informants are necessary to shed light on these elements and gain a deeper understanding of these process-related interactions in practice.

Interviews with key informants concerned nine interviews, of which three interviewees were associated with each case (Table 4). The interviews lasted approximately two hours and were conducted in-person between 7 November 2018 and 10 December 2018. The analysis, which involved manual coding, proceeded in accordance with a standard iterative process typically employed for qualitative data. The semi-structured interviews were conducted using a preconceived interview protocol. The questions were formulated in line with relevant concepts gathered from theories on actor analysis, network analysis, and decision-making processes and circularity. In order to

Table 3. Data analysis: coding of interview data for the decision-making process visualization.

Concepts decision-making process	Visualization		Retrieved from interview
Actor	Involved	- Open node	- Consulted during decision-making
	Influence	- Filled node	- Participated in decision-making
Round	Circle		Decision regarding a circular strategy or subsequent pattern, design strategy
Time	Position of round		Phase of construction process in which the decision was made
Implementation	Colour of round	- Black	- Decision implemented
		- Grey	- Decision not implemented

Table 4. Cases included in the case study research.

Case	Type	Year	Location	Standard	Interviewees
Case I: Townhall Brummen	Renovation	2013	Brummen	Cradle-to-cradle certified	Two contractors, designer
Case II: The Green House	New-build	2018	Utrecht	Building circularity index	Client, designer, project manager
Case III: EDGE Olympic	Transformation	2018	Amsterdam	BREEAM Excellent	Client, designer, dismantler

deal cautiously with the sample size of nine interviews, including three interviews per case, information about involved actors, their influence, relations and role within the decision-making, was compared and cross-checked with the interviews and other data sources.

Case study research

The case study research evaluates three circular building cases in the Netherlands (Table 4). These cases are Townhall in Brummen built in 2013, The Green House in Utrecht built in 2018, and EDGE Olympic in Amsterdam built in 2018. These cases were selected based on specific criteria: an ambition for circularity, recent realization (after 2010), and a similar context and comparable construction process. Notwithstanding these aforesaid similarities, it must be noted that these cases concern different types of projects, that is, a renovation project, a new-build project, and a transformation project. Therefore, one must exercise caution regarding the generalisability of the results on the identified multi-actor environment and decision-making process in relation to these different contexts.

Case description

Case I – Townhall in Brummen – is a renovation project, that includes: 1) demolition of the existing municipality building, (2) preservation of the existing monumental villa, and (3) construction of a new U-shaped municipality building surrounding the monumental villa. The building includes office spaces, meeting rooms and public reception areas. The project was initiation by the client (the municipality, a public owner-user) by means of a public tender in which sustainability was included as one of the criteria for selection. More specifically the client demanded a cradle-to-cradle certified building with a temporary lifetime. In other words, the temporary lifetime demanded that provisions for demountability and reuse of materials afterwards needed to be included in the design. The new municipality building's primary structure consists of a timber structure in combination with steel connections. Its façade comprises a combination of glass and wooden-shutter elements. Other materials include a green roof and bamboo floor finishings. The process of timely demolishing and accommodating the new building attached to the monumental building provided some complexity in terms of planning. The accommodation of the municipality needed to be continuously secured. In the end, however, the building was completed in just 7 months. A design and build contract was used, which demands the early involvement and central positioning of a contractor, who coordinates between the client and designer. While the client has a strong influence over the process, they are not involved directly (Figure 2).

Case II, The Green House, is a new-build project which accommodates a restaurant, meeting rooms, and a greenhouse to grown vegetables and herbs. It was built with a temporal lifespan in mind, which was not necessarily informed by sustainability concerns, but rather was determined by a dictate from the urban planning scheme that stated that another office building was to be constructed in the same location 15 years later. The Green House was constructed simultaneously alongside the transformation of a former barracks building into government offices. Both buildings were part of the same project, which was publicly tendered. This resulted in a slightly similar actor environment and parallel construction processes. The designer was involved in the design of both buildings, which provided opportunities to reuse materials from the barracks building in The Green House, such as the reused glass façade elements. The Green House consists, amongst others, of a prefab concrete base, a demountable steel structure of columns and beams, a steel roof frame, a prefab timber frame flooring and wall structure, and reused concrete tiles as floor finishing. The Green House was realized in a Design, Build, Finance, Maintain and Operate-contract (DBFMO). This type of collaboration typically incentivizes actors to consider the long-term or entire life cycle of the building. It usually results in the clients having limited influence over the process, and, indeed, in this particular case, the client (a public owner, not a user) was not directly involved. The client only, during the initiation of the project, demanded that the building should be temporal and demountable (no waste should remain on-site). Rather, a consortium comprising several actors was established, in which the contractor became the owner and was responsible for the operation phase (Figure 3).

The EDGE Olympic building (Case III) concerns a transformation project. An existing office building was renovated and transformed, which included the construction of entirely new floors on top of and adjacent to the existing building. The transformed building would provide office space to multiple companies, with the inclusion of a shared space with different types of meeting rooms. The EDGE Olympic building was designed to meet the BREEAM Excellent standard. The project was a traditional collaboration, in which

Figure 2. Townhall in Brummen (Case I). (© 2013 Léontine van Geffen-Lamers).

the client (a private owner-user) collaborated intensively with a designer and some specialists during the preparation and design phase. Afterwards, when construction began, the contractor also joined the process. During the whole process, the client was involved in all phases. The existing building was primarily preserved, except for its natural stone façade elements that were recycled and applied as flooring inside the building. The additionally added floor on top of the existing building was made of a prefabricated lightweight timber structure designed with demountable connections and a façade consisting of glass elements (Figure 4).

Findings

Composition of multi-actor environment in circular construction processes

The three cases demonstrated that each multi-actor environment comprised different actors, which is to say that each case had its own distinctive network made up of specific types of actors. These types of actors can be organized into the following categories: experts with knowledge of circularity, conventional actors who have acquired knowledge on circularity, and conventional actors with either limited or no knowledge of circularity. Both the level of knowledge and the question of whether actors acquired knowledge on circularity were concluded from the interviews. In the interviews, the knowledge that was displayed by certain actors about circular strategies and subsequent design strategies and patterns was collected.

Figure 5 shows the networks that were identified in the case study research. All three cases involved, to varying degrees, experts who had knowledge on circularity. In Case I, these expert actors were: a circularity expert, consultant, and dismantler. Case II had a circularity expert, while Case III had: a circularity expert, dismantlers, an investor, and reclamation experts. Moreover, these cases also involved conventional actors who had acquired knowledge of circularity. In Case I, this involved two specialists and a supplier. In Case II, there was a contractor, subcontractor, and

Figure 3. The Green House in Utrecht (Case II). (© 2018 Lucas van der Wee).

suppliers. And in Case III, the subcontractor had such knowledge. As indicated by the size of the nodes, these actors exerted moderate or little influence over decision-making in these cases. Finally, these cases involved conventional actors who had little or no knowledge of circularity. In Case I, these actors were the client, contractor, designer, project manager, specialists, subcontractor, and supplier. In Case II, these were the client, contractor, designer, government, legal officer, project manager, and specialists. And in Case III, these were the client, contractor, designer, government, and specialists.

There was a strong sense of coordination and exchange of information (thick lines) on circularity within the project team primarily, and to a lesser extent between the project team and surrounding actors. The following surrounding actors did coordinate frequently with actors in the project team (these do not all pertain to actors who had the resources to implement circularity): a circularity expert, client, consultant, and supplier (Case I); a supplier (Case II); a circularity expert, contractor, and dismantler (Case III). From these cases, it remains uncertain whether already established relations are beneficial for implementing circularity. Relations outside the network were established to facilitate the reuse of secondary components. Based on these cases, this was facilitated by two aspects: (1) the proximity of secondary components in terms of distance, and (2) the external network of the involved actors. With respect to all three cases, it appears that both contractors and designers helped to organize the reclamation of secondary components.

The actor positioned in the centre, that is, the actor with the highest number of relations and highest number of relations that display frequent coordination, was, respectively: the contractor (Case I), project manager (Case II), and client (Case III). In Cases I and III, the centrally positioned actors also exerted the highest influence over decision-making. Regarding Cases I and III, the actor in the central position, was formally determined based on the type of building contract and the attendant responsibilities. In Case I, this actor (contractor) was responsible for designing and building as well as interacting with other actors in their capacity as contractor-subcontractor. In Case II, the centrally positioned actor and the actor with the highest influence on decision-making was divided between two actors: the project manager and the contractor.

Figure 4. EDGE Olympic building in Amsterdam (Case III). (© 2019 Ossip van Duivenbode).

The analysis of the cases demonstrates that those actors that were part of the project team had a greater influence on decision-making. The project team in each case consisted mainly of conventional actors who lacked substantial knowledge on circularity: clients, contractors, designers, project managers, and specialists in building physics and structural engineering. Notwithstanding this finding, some actors who were not part of the project team were nevertheless found to have moderate influence: in Case I, this was a circularity expert, client, consultant, and a supplier; in Case II, this was a subcontractor; and in Case III this was a dismantler. Interestingly, these actors were all either expert actors or conventional actors who had acquired knowledge on circularity. Thereby, these actors all provided circularity-related resources.

Decision-making and implementation of CSs in the construction process

The research into how the decision-making process evolved over time analyzed the assumed benefit of early decision-making with respect to circularity. Figure 6 shows how the decision-making process evolved over time for all three cases. As one can discern, several rounds of decision-making took place to decide on the beginning and end-of-life scenarios. These distinct rounds were pinpointed by identifying decision-making on CSs, as determined by the analytical framework. As can be seen in Figure 6, the decision to implement CSs (1) maximizing material and energy efficiency and dematerialization were made relatively early on in all the considered cases. Hence, these rounds are positioned in the pre-phase. However, these cases all applied this strategy differently in practice (see also Table 5), in order to reach the overarching goal of preventing and reducing material use: applying a lightweight construction (Case I); reducing the dimensions of structural components (Case II); and by the *in-situ* reuse of an existing building (Case III).

Although decisions on the CS (2) functionality without ownership and extending product value were made for all three cases, their implementation differed.

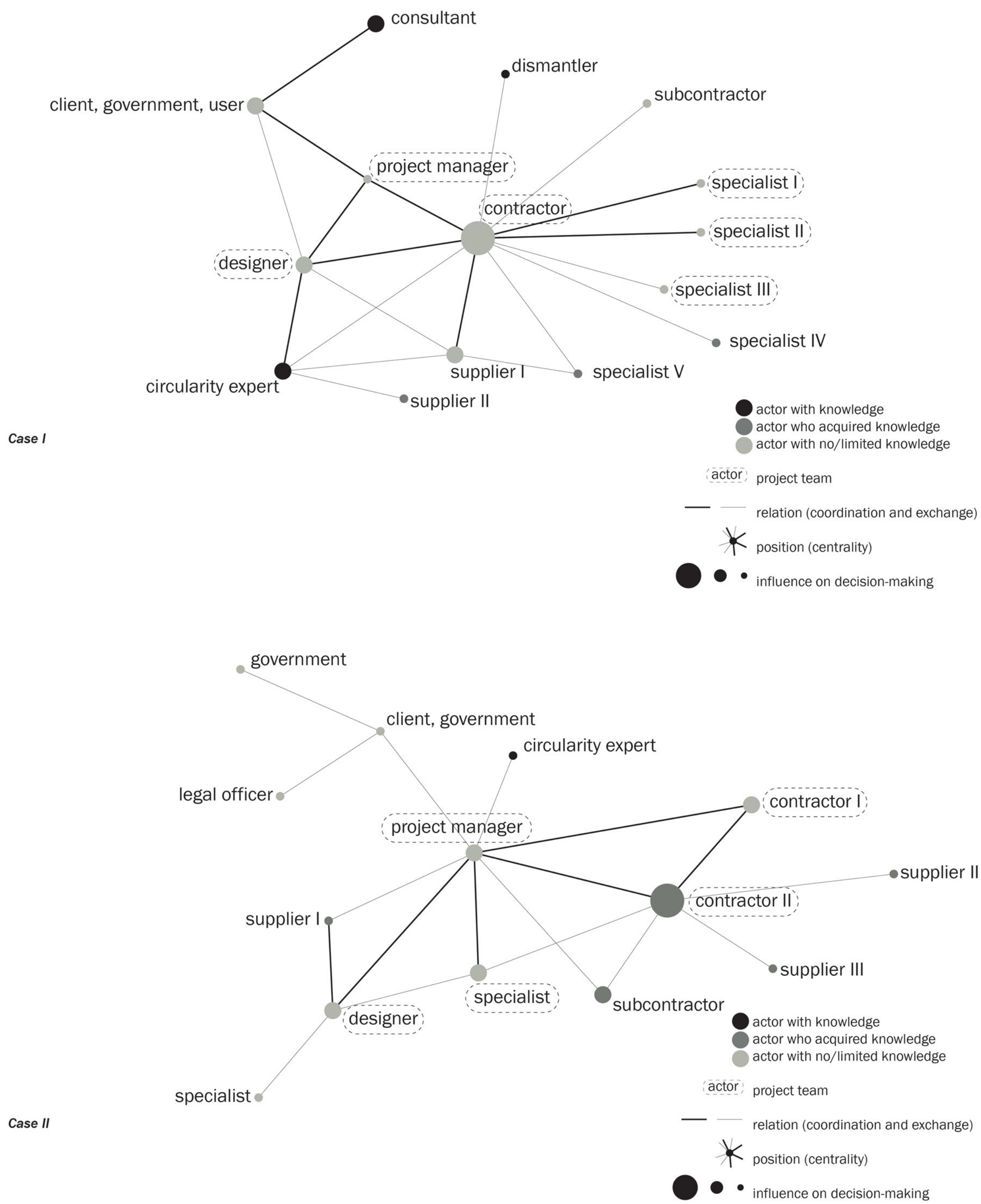

Figure 5. Multi-actor environment including involved actors, their relations, positions, and influence on decision-making, for Case I (Townhall Brummen), Case II (The Green House), and Case III (EDGE Olympic).

Cases I and II used CS (2) to make agreements on delivery and the taking back of components, determine the end-of-life scenarios (i.e. securing demountability) and lay down ownership. Ultimately, however, this CS was not properly implemented in Case I. Case III involved several expert actors deciding on CS (2) as a beginning-of-life scenario for the building, resulting in the implementation of a long-life design strategy. These cases demonstrate that CS (2) was effectively implemented if the decision round took place in the initial stages of the project. Later in the process, the opportunities for implementing this strategy appeared to be limited due to the risks associated with non-traditional ownership structures.

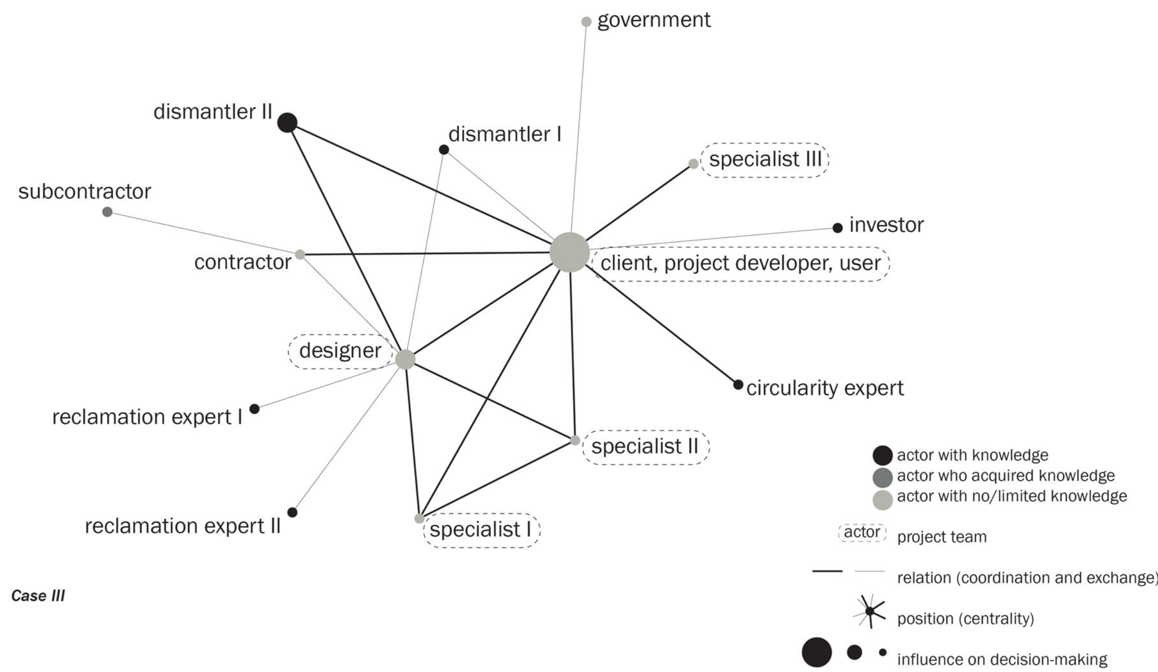

Figure 5. Continued

Whether or not the CS (3) extending resource value and industrial symbiosis was properly applied in the three cases is questionable, insofar as its implementation predominantly resulted in downcycling. More specifically, the secondary materials degraded after recycling in Case III, while, in regards to Case I, some materials were applied based on their ability to degrade biologically at the end of their lifespan. This resulted in the use of bio-based materials. In Case II, the decision was taken to separate biological and technical nutrients, in order to facilitate recycling.

In addition to these findings on the relationship between decision-making on certain CSs and their subsequent implementation, findings related to actors' involvement over time were also considered. Specifically, the examined cases show that designers and contractors were involved in the pre-phase. Moreover, in Case I, a specialist and supplier was involved in the initial stages. In Case II, a circularity expert, specialist, and supplier were involved at this early stage, while in Case III a dismantler, reclamation expert, and specialist were involved during the initial stages. With respect to all three cases, the client initiated the project by proposing either a circular or sustainability-based vision, centred on tendering a sustainable building, demanding a demountable building, or demanding closed resource loops.

As can be discerned in Figure 6, the involvement of certain actors does not necessarily indicate that these actors had any influence over decision-making (as indicated by the non-filled and filled circles). Certain actors were indeed involved in several rounds while simultaneously exerting (albeit in a limited sense) influence over decision-making. In Case I, this concerned a client, contractor, designer, and supplier. In Case II, a contractor, designer, project manager, specialist, and supplier exerted influence over decision-making, while a client, designer, and dismantler occupied this position in Case III. The actors who were involved (albeit to a limited extent), but yet had no influence over decision-making are as follows: a circularity expert, dismantler, specialist, and supplier (Case I); a circularity expert, suppliers, and a subcontractor (Case II); and a circularity expert, contractor, reclamation experts, specialists, and a subcontractor (Case III).

Cases I and III point towards some degree of ad hoc involvement (often in the form of consultation) by certain actors. This often occurs in instances in which decision-making is hampered because those actors that are already involved tend to have limited knowledge of a certain CS. In Case I, a circularity expert became involved due to the occurrence of CS (2) the problem of implementing a non-traditional ownership structure as part of a product-as-a-service. Furthermore, in Case I, a supplier became involved to provide knowledge about CS (1) on the structural application of timber as a lightweight construction material. In this specific instance, the supplier did influence decision-making in this round. Case III saw

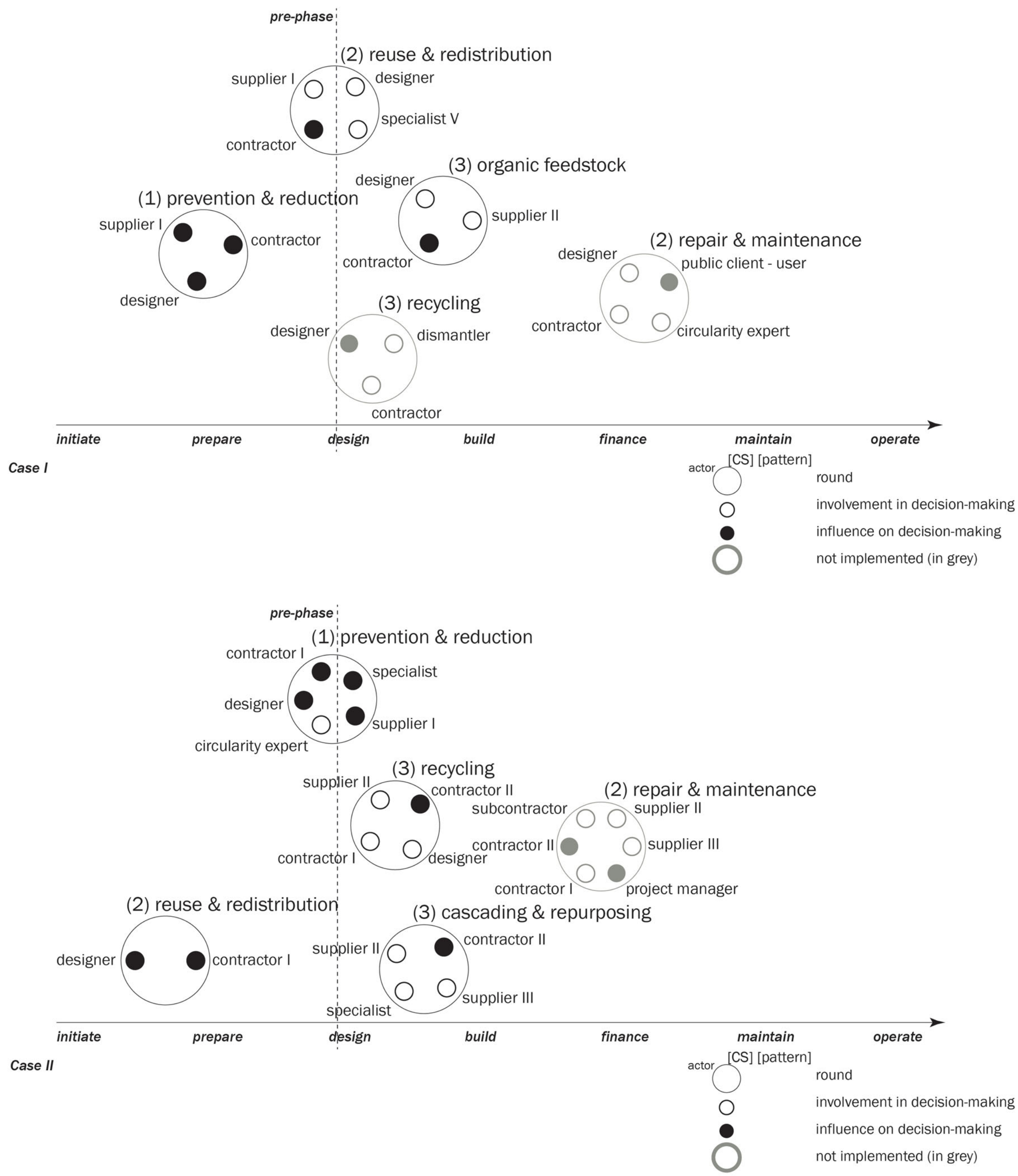

Figure 6. Decision-making process including involved actors, topics (CSs and accompanying pattern), and rounds positioned over time, for Case I (Townhall Brummen), Case II (The Green House), and Case III (EDGE Olympic).

the involvement of a dismantler in the initiation phase, who attempted to advise decision-making on CS (1) in relation to components of the existing building that were suitable for reuse. However, ultimate decision-making power continued to be held by the client and designer.

Case II also saw the involvement of an actor after the design-making process, who subsequently then also influenced the decision-making process. That is to say, upon completion of the design/build phase a second contractor became involved, who influenced and accelerated the decision-making process with respect to CS (2). Their involvement specifically concerned the implementation of reuse at the end of life, both in terms of demountability and take-back schemes. The influential position held by this actor is likely derived from their formal position as both the owner and user of the building.

Table 6 provides an overview of the CSs that were decided upon and, in most cases, implemented in relation to the layers of the buildings in the three cases. Some CSs were primarily applied to short-lived

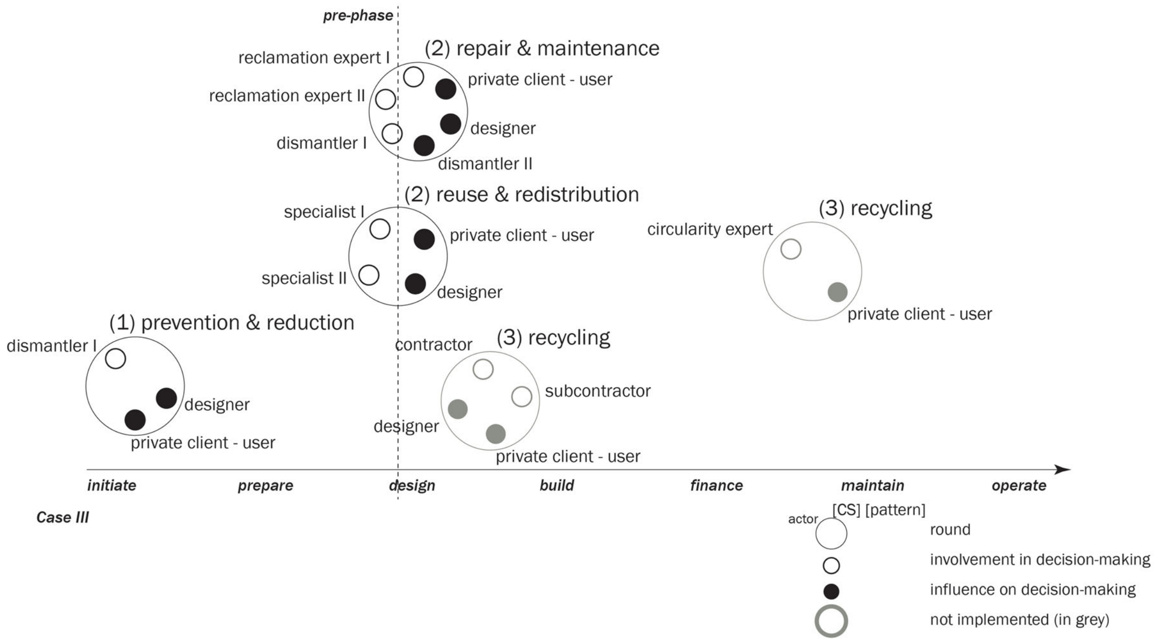

Figure 6. Continued

layers, while others were mostly applied to long-lived layers. As one can see, CSs (1) and (2), whose aim was to facilitate reduction and reuse, were primarily applied to long-lived layers. Conversely, CSs (2) and (3), which sought to facilitate reuse and recycling, were decided upon and implemented in relation to short-lived layers, although the complete implementation of CSs (2) for short-lived layers proved to be difficult.

These findings demonstrate that in these cases the pre-phase was important for securing circularity and in terms of making provisions for both the beginning and end-of-life scenarios of the building. For these cases, the study found that all rounds that took place in the initial stages were implemented. Conversely, those rounds that took place later in the project were not all implemented. Of those rounds that took place later on in the construction process but were implemented, these were mainly related to the financial or documentation elements associated with integrating CSs (such as a decomposition manual) and primarily concerned short-lived layers. The rounds that pertained to material elements (take-back management, waste handling and processing) and which took place later on in the process, were not wholly implemented.

Discussion

Implications for practice and research

The case study research demonstrates that some conventional actors acquired knowledge of circularity, which is in accordance with extant research in this area (Munaro *et al.* 2020). Moreover, these actors already sought to incorporate these renewed insights into the development and implementation of circular strategies. This suggests that when all conventional actors acquire in-depth knowledge to implement circularity themselves, as opposed to relying on expert actors, then such experts become superfluous insofar as circularity has become common practice.

The relevance of the initiating role played by clients is also consistent with prior research on innovation processes in the construction industry (Wamelink and Heintz 2015, Lindblad and Gustavsson 2020). Indeed, in these cases, the client provides the "problem as a point of departure" by stating the ambition on circularity. This study shows that, irrespective of whether the client takes the initiative in terms of promoting circularity, other actors, such as the contractor and project manager, can still act on and steer towards adaptation and implementation of certain CSs. These actors positioned centrally in the network can be indicated as important nodes who influence decision-making.

Of course, universities have an important role to play in terms of providing conventional actors (i.e. designers, contractors, specialists) with a sound knowledge of circularity via their programmes of study. Along with providing these conventional actors with the requisite knowledge and skills on circularity. Munaro *et al.* (2020) argue that a change of mentality is ultimately required if these actors are to truly contribute to the transition towards a circular economy.

Table 5. Summary of applied CSs in relation to the building's layers and its implementation in concrete terms.

Application in	CS	Pattern	Design strategy	Implementation in concrete terms	Layers
Case I: Townhall Brummen					
Pre-phase	CS (1): de-materialization	Prevention & reduction	Design for resource efficiency	Reduction of dimensions of structural components, lightweight construction material	Structure
	CS (3): industrial symbiosis	Recycling	Design for technical cycles	Recycled masonry from existing office	Space plan
Post-phase	CS (2): functionality without ownership/product service system (PSS)	Repair & maintenance	Design for component extension	Take-back of components and offering a product as a service	Skin, services
	CS (2): extending product value	Reuse & redistribution	Design for component extension	Demountable connections, reusable measurements, standardisation, separable components	Structure, services
	CS (3): extending resource value	Organic feedstock	Design for biological cycles	Application of bio-based materials	Space plan, stuff
Case II: The Green House					
Pre-phase	CS (1): de-materialization	Prevention & reduction	Design for resource efficiency	Reduction of dimensions of structural components	Structure
	CS (2): extending product value	Reuse & redistribution	Design for long-life components	Reuse of second-hand components from different locations, that is, pavement, furniture	Skin, space plan, stuff
	CS (3): industrial symbiosis	Cascading & repurposing	Design for technical cycles	Recycled finishings, that is, recycled fishnet carpet and recycled wall finishings	Space plan, stuff
Post-phase	CS (2): functionality without ownership/product service system (PSS)	Repair & maintenance	Design for component extension	Take-back of components and offering a product as a service, demountable components by means of stacking separable into components, standardized grid and components	Structure, skin, services
	CS (3): extending resource value	Recycling	Design for technical cycles Design for biological cycles	Technical and biological nutrients separable into homogenous materials	Skin, services, space plan
Case III: EDGE Olympic					
Pre-phase	CS (1): maximize material and energy efficiency	Prevention & reduction	Design for resource efficiency	Transformation of existing building	Structure
	CS (2): extending product value	Repair & maintenance	Design for long-life buildings	Reuse of existing structure	Structure
	CS (3): extending resource value	Recycling	Design for technical cycles	Recycling of façade tiles into floor	Space plan
Post-phase	CS (2): extending product value	Reuse & redistribution	Design for building life extension	Addition is designed to be demountable and separable into biological and technical nutrients, services mechanically connected (not integrated)	Skin, services
	CS (3): extending resource value	Recycling	Design for technical cycles	Cradle-to-cradle materials for finishings, materials documented in a material passport	Space plan

Table 6. Implementation of CSs for the building layers in each case.

Site	Structure	Skin	Services	Space plan	Stuff
Case I	(1) reduce, (2) reuse	(2) reuse	(2) reuse	(3) recycle	(3) recycle
Case II	(1) reduce, (2) reuse	(2) reuse, (3) recycle	(2) reuse, (3) recycle	(2) reuse, (3) recycle	(2) reuse, (3) recycle
Case III	(1) reduce, (2) reuse	(2) reuse	(2) reuse	(3) recycle	

CS (1) maximize material and energy efficiency and dematerialization.
CS (2) functionality without ownership/product service system (PSS) and extending product value.
CS (3) extending resource value and industrial symbiosis.

The cases examined in this paper also testify to the fact that circularity has not yet become common practice in the building industry, and that, in fact, circular knowledge is still largely incorporated in the development of projects through experts and actors centrally in the network. While the role of an expert actor or actors who seek to drive a swift implementation of circular strategies, can be occupied by a range of different actors, it demands a central position within the multi-actor environment. In all of the three cases under examination, the actors that were part of the project team had a greater influence on decision-making, but yet, as aforesaid, these conventional actors lacked expertise on circularity. Ideally, expert actors who are capable of implementing CSs should become part of the project team, so that they can more effectively influence decision-making.

Moreover, these cases particularly underscore that if these experts are involved in the pre-phase of the process, their contribution towards circularity is greatly enhanced. This is in accordance with the findings of Sanchez and Haas (2018), who also concluded that CSs will be more successfully implemented if attention to decision-making rounds (which in their work are defined as gates) as well as the incorporation of appropriate planning methods are included in the pre-phase of a construction project. Indeed, appropriate decision-making and planning in the pre-phase have been shown to contribute to the successful implementation of circularity and are a determining factor in a project's success (Sanchez and Haas 2018). Setting the major decisions for the project in the pre-phase, alongside securing the commitment of actors to contribute their resources to the project, could help to overcome, or at the very least reduce, the risk that pressure-based elements of a project, such as time and money, can lead to myopic decisions based on appearances as opposed to long-term impact (Hart *et al.* 2019).

With respect to the wider construction industry, this study generates insight into how to accelerate the transition process away from a linear process towards a circular construction process. As the three cases clearly illustrate, (expert) actors can influence decision-making on circularity by virtue of their position in the project team, as well as via their relations, or associations with actors with influential resources (i.e. building policy and legislation). Furthermore, this transition constitutes a profound shift of attention towards the end-of-life phase of a building. The end-of-life phase should be integrated into the pre-phase of the construction process, given that early decision-making on the implementation of CSs can potentially help to mitigate the perceived risks associated with the involvement of unconventional actors (i.e. dismantlers), non-traditional ownership structures (PSS), and secondary materials.

Limitations and suggestions for further research

While this study focussed on the types of actors involved in circular construction processes, as well as underscoring the importance of certain actors being involved in the initial stages of the decision-making process, it did not specifically address how these actors should be involved or how they should specifically influence decision-making. While the actor analysis affords certain means through which to enhance influence – by means of relations in the network, and by occupying a central position in the network – and the decision-making process demonstrates how involvement and influence change over time, further research is required in order to address two outstanding questions. First, the research could explore how actors gain influence in the decision-making process of circular building projects. Secondly, the research could attempt to establish the presumed benefit of involving certain actors in the project team, as well as determining the benefit of engaging actors (who are beneficial to implementing circularity) in the network in such a way that they are not only involved but also have influence.

Due to the qualitative nature of the approach adopted in this study, one must exercise caution regarding the generalisability of the results on the identified actor analysis and decision-making process in relation to different contexts. Although the researchers did compare and cross-check data from interviews and secondary sources within the cases, it must be noted that the visualization of both the multi-actor environment and decision-making process is a representation of a chaotic and dynamic reality in which the researcher is highly dependent on valuable information from involved actors. Hence, studies on similar initiatives in other regional contexts would allow for a more detailed comparison of the implementation processes of circular strategies, which, in turn, would enhance the generalisability of the results from this study.

Conclusion

From the case analysis, one can conclude that the following actors should be involved and play an influential role in the design-making process of circular building projects: (i) conventional actors who have acquired knowledge on circularity; and (ii) expert actors in the role of advisors, consultants, and assessors. Moreover, based on both the cases examined in this study and the current state of the construction industry itself, involving the following expert actors would also be greatly beneficial: circularity experts, dismantlers, investors, and reclamation experts. Furthermore, these cases also testify to the fact that implementation is facilitated by the involvement of the following conventional actors, but, importantly, only if they have knowledge of circularity: specialists, subcontractors, and suppliers. Finally, actors centrally positioned in the network can accelerate the implementation of circularity by exploiting their position to acquire support from others and mobilize the entire network.

Although the key actors responsible for implementing CSs differ slightly across each case, early decision-making appears to be a key determining factor in the success of a circular building project. Decision-making with respect to circularity is based on the following CSs: (1) maximizing material and energy efficiency and dematerialization; (2) functionality without ownership/product-service system (PSS) and extending product value; and (3) extending resource value and industrial symbiosis. Implementation of these CSs is beneficial if decisions on CSs are made early in the process (preferably in the pre-phase). Subsequently, during the pre-phase, these expert actors and other actors with expertise on circularity can help in terms of deciding between the various beginning and end-of-life scenarios. The consequence of this is that most decisions concerning reduction, reuse, and recycling with respect to short- and especially long-lived layers should be carried out early on in the construction process.

Disclosure statement

The authors declare that they have no known competing financial interests that may have influenced the work reported in this paper.

Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

References

Adams, K.T., *et al.*, 2017. Circular economy in construction: current awareness, challenges and enablers. *Proceedings of the Institution of Civil Engineers*, 170 (1), 15–24.

Addis, B., 2006. *Making reclamation, reuse and recycling happen. Building with reclaimed components and materials*. London, UK: Earthscan, 55–86.

Aminoff, A., Valkokari, K., and Kettunen, O., 2016. Mapping multidimensional value(s) for co-creation: networks in a circular economy. *International Federation for Information Processing*, 480, 629–638.

Bocken, N.M.P., *et al.*, 2014. A literature and practice review to develop sustainable business model archetypes. *Journal of Cleaner Production*, 65, 42–56.

Bocken, N.M.P., *et al.*, 2016. Product design and business model strategies for a circular economy. *Journal of Industrial and Production Engineering*, 33 (5), 308–320.

Borgatti, S., *et al.*, 2009. Network analysis in the social sciences. *Science*, 323 (5916), 892–895.

Brand, S., 1994. *How buildings learn - what happens after they're built*. London, UK: Penguin Books.

Enserink, B., *et al.*, 2010. Actor analysis. In: *Policy analysis of multi-actor systems*. Hague, The Netherlands: Lemma, 79–108.

Freeman, R.E., 1984. *Strategic management. a stakeholder approach*. Boston, MA: Pitman Publishing.

Galvão, G.D.A., *et al.*, 2018. Circular economy: overview of barriers. *Procedia CIRP*, 73, 79–85.

Geissdoerfer, M., *et al.*, 2017. The circular economy: a new sustainability paradigm? *Journal of Cleaner Production*, 143, 757–768.

Gorgolewski, M., 2008. Designing with reused building components: some challenges. *Building Research & Information*, 36 (2), 175–188.

Gorgolewski, M. and Ergun, D., 2013. Closed-loop materials systems. In: *Sustainable building conference*. Coventry, UK: Coventry University, 235–243.

Hart, J., *et al.*, 2019. Barriers and drivers in a circular economy: the case of the built environment. *Procedia CIRP*, 80, 619–624.

Iacovidou, E. and Purnell, P., 2016. Mining the physical infrastructure: opportunities, barriers and interventions in promoting structural components reuse. *Science of the Total Environment*, 557–558, 791–807.

Joensuu, T., Edelman, H., and Saari, A., 2020. Circular economy practices in the built environment. *Journal of Cleaner Production*, 276, 1–20.

Johansen, E. and Wilson, B., 2006. Investigating first planning in. *Construction Management and Economics*, 24 (12), 1305–1314.

Kibert, C.J., 2013. *Sustainable construction: green building design and delivery*. Hoboken, NJ: Wiley.

Klijn, E.H. and Koppenjan, J., 2016. *Governance networks in the public sector*. New York, NY: Routledge.

Leising, E., Quist, J., and Bocken, N.M.P., 2018. Circular economy in the building sector: three cases and a collaboration tool. *Journal of Cleaner Production*, 176, 976–989.

Lindblad, H. and Gustavsson, T.K., 2020. Public clients ability to drive industry change: the case of implementing BIM. *Construction Management and Economics*, 39, 21–35.

Lüdeke-Freund, F., Gold, S., and Bocken, N.M.P., 2018. A review and typology of circular economy business model patterns. *Journal of Industrial Ecology*, 23, 36–61.

MacArthur, J., 1997. Stakeholder analysis in project planning: origins, applications and refinements of the method. *Project Appraisal*, 12 (4), 251–265.

McDonough, W. and Braungart, M., 2009. *Cradle to cradle: remaking the way we make things*. London, UK: Vintage Books.

Mitroff, I. I., 1983. *Stakeholders of the organizational mind. Toward a new view of organizational policy making*. San Francisco, CA: Jossey-Bass.

Mulhall, D. and Braungart, M., 2010. *Cradle to cradle criteria for the built environment*. Nunspeet, The Netherlands: Duurzaam Gebouwd.

Munaro, M.R., Tavares, S.F., and Bragança, L., 2020. Towards circular and more sustainable buildings: a systematic literature review on the circular economy in the built environment. *Journal of Cleaner Production*, 260, 1–25.

Ness, D.A. and Xing, K., 2017. Toward a resource-efficient built environment: a literature review and conceptual model. *Journal of Industrial Ecology*, 21 (3), 572–592.

Osmani, M., Price, A., and Glass, J., 2006. Architect and contractor attitudes to waste minimisation. *Proceedings of the Institution of Civil Engineers*, 159 (2), 65–72.

Pomponi, F. and Moncaster, A., 2017. Circular economy for the built environment: a research framework. *Journal of Cleaner Production*, 143, 710–718.

Ridder, de H., 2018. Naar een Circulaire Bouwsector. *In*: P. Luscuere, ed. *Circulariteit: Op Weg Naar 2050?* Delft, The Netherlands: TU Delft, 209–217.

Ritala, R., *et al.*, 2018. Sustainable business model adoption among S&P 500 firms: a longitudinal content analysis study. *Journal of Cleaner Production*, 170, 216–226.

Ruijven, V., *et al.*, 2015. Multidisciplinary coordination of on-scene command teams in virtual emergency exercises. *International Journal of Critical Infrastructure Protection*, 9, 13–23.

Sanchez, B. and Haas, C., 2018. Capital project planning for a circular economy. *Construction Management and Economics*, 36 (6), 303–312.

Scholes, K., 1998. Stakeholder mapping: a practical tool for managers. In: V. Ambrosini, G. Johnson, and K. Scholes, eds. *Exploring techniques of analysis and evaluation in strategic management*. Essex, UK: Prentice Hall/Financial Times, 152–168.

Stahel, W.R., 2016. The circular economy. *Nature*, 531, 435–438.

Teisman, G.R., 2000. Models for research into decision-making processes: on phases, streams and decision-making rounds. *Public Administration*, 78 (4), 937–956.

Tukker, A., 2015. Product services for a resource-efficient and circular economy – a review. *Journal of Cleaner Production*, 97, 76–91.

Tura, N., *et al.*, 2019. Unlocking circular business: a framework of barriers and drivers. *Journal of Cleaner Production*, 212, 90–98.

Wamelink, H. and Heintz, J., 2015. Innovating for integration: clients as drivers of industry improvement. *In*: *Construction innovation*. Chichester, UK: John Wiley & Sons, 149–164.