A circular business ecosystem approach towards achieving high value use of salvaged building materials in the Dutch built environment

The case of Dutch demolition contractors

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Executive Summary

Like Industrial Ecology research makes use of the analogy between closed-loop systems in nature and material flows in the economy, business ecosystem literature uses the analogy of ecosystems to explain cross-industry cooperative behavior. It tries to explain how several cross-industry companies jointly create new solutions to capitalize on new trends. Synergizing the concepts of business ecosystems and the circular economy leads to a new definition of a circular business ecosystem. A circular business ecosystem can be defined as *'a set of actors that jointly work towards achieving the collective outcome of closing, narrowing, slowing or generating the loop on resources establish a circular innovation (e.g. product or service), initiative or project'*. Any company can initiate a circular business ecosystem by creating an ecosystem of actors with complementary capabilities, that share a mutual goal, and jointly work towards creating a project, service, initiative or project that embraces the principles of the Circular Economy (e.g. reuse, refurbish, recycle etc.). The creation of a circular business ecosystem involves new configurations of value chains, actor roles and the application of new circular economy business models.

There is a lack of understanding of networks and cooperation required to operate circular strategies in the Dutch built environment. Since demolition contractors are salvaged building material suppliers, it is interesting to explore how these companies orchestrate their circular business ecosystems that surround these material flows. Therefore, the main question of this research is: *How can high value reuse and recycling of salvaged building materials and components be achieved in the Dutch C&D environment, following a circular business ecosystem perspective?* To apply a circular business ecosystem perspective, an established 6C-framework for analyzing IoT-business ecosystems is extended to a framework for circular business ecosystems by an extensive literature review on circular (business) ecosystems. This includes the dimensions context, construct, configuration, cooperation, capabilities, and change. Additionally, this study has a qualitative research approach. This includes a case study analysis of four demolition contractors. Data was retrieved from semi-structured interviews and additional secondary data. Hybrid coding is used as a strategy to retrieve meaningful information from the data. This involves a combination between the deductive coding strategy to use a pre-set code scheme, and the inductive coding strategy open coding.

From the data results that the demolition contractors have constituted several circular value chains and engaged in several circular demolition (and construction) projects. The projects could be distinguished into temporary business ecosystems and the circular value chains into enduring circular business ecosystems. Project collaborations generally consisted of a small heterogeneous group of C&D actors that work towards achieving circularity of building materials in an early stage of the design process. Enduring circular business ecosystems refer to the establishments of value chains that include high value reuse, resell, return, refurbishment, or recycling of salvaged building materials. These circular value chains are mainly organized by demolition contractors themselves in collaboration with a few other C&D actors.

From the results follows that several things particularly important in these ecosystems. First, the mutual sharing of knowledge, skills, and experiences. Second, an open, transparent, and flexible attitude towards each other. Third, trust in each other and each other's intentions. Fourth, a circular mindset of all ecosystem actors and fifth, to jointly set common circularity goals in projects. Lastly, an atmosphere of joint learning and problem solving, and possible co-creation helps to realize goals

or ambitions set. These also implies acting beyond striving solely for own personal gains. Therefore, open budgeting is preferred as it provides insights in costs that needs to be covered, creating grounded business case with fair returns for all ecosystem actors.

Furthermore, from the results follows that high value application of salvaged materials is most cost and environmental efficient when the loop is closed locally. Hence, local reuse and reprocess of salvaged building materials is preferred. Accordingly, circular strategies to achieve high value handling of salvaged building materials is subdivided geographically. This distinguished the circular strategies applied to salvaged materials into *on-site*, *close-by site* (i.e. local) and *away from site* (i.e. non-local) strategies. In addition, to achieve the largest extent of high value use of salvaged materials requires several pre-dismantling activities.

Before dismantling, the salvaged materials and components need to be inventoried (i.e. by pre-demolition audits). Next, this inventory needs to be visible at an online marketplace for potential buyers. This enables potential matchmaking with (several) local construction and/or project(s). Subsequently, discuss the possible options to process or reuse (parts of) the salvaged materials on-site. *On-site* options are for example, leaving part of the structure in-tact or recycling concrete with a smart crusher. A *close-by* site option is for example reusing part of the structure in (a local) new construction project(s). This option needs possibly temporary storage in case salvaged materials are dismantled before construction. An *away-site* option is for example to choose high value recycling for gypsum. If no matchmaking occurs the architect can still opt to create a design by describing functionalities without strictly specifying material choice. Accordingly, if it occurs that salvaged are released close before the building phase, these materials can be used.

Following the findings of this study, several practical recommendations followed. First, to accommodate the necessary knowledge and experience exchange to apply salvaged materials directly in a new construction project, establishing collaboration in the very beginning of a project is regarded as fruitful. Suitable collaboration forms are those that have early-contractor involvement. These collaborations foster knowledge and experience exchange, joint problem solving and co-creation to realize ambitions. Examples of this early-contractor involvement collaboration forms are a construction team (in Dutch: bouwteam) or testing ground set-up (in Dutch: proeftuin). Second, it is recommended to work towards a (national) database that entails a salvaged material inventory of all future demolition projects, prior to demolition. This database should then be accessible to architects, building contractors, clients, and project developers. Last, it is recommended to foster regional refurbishment hub development open for several demolition (and building contractors) to entry, because increases economies of scale and logistic efficiency.

Lastly, this study provides the following further research recommendations. First, the findings suggest that on project basis, early-contractor involvement before the design phase is a very suitable collaboration form to achieve a maximum of high value reuse and recycling. Hence, it is recommended to dive deeper into the different configurations of early-contractor involvement (e.g. construction teams, testing ground set-ups, consortia) and estimate which form is most fruitful to exploit mutual benefits and achieve common circularity goals set. For example, further research could dive into exploring the key success factors in these collaborations. Some findings of this study (e.g. transparent and open attitudes and the use of open budgeting) provide already some starting points for hypothesis. Second, regarding business (model) research the 6C-framework applied in this study can provide an additional layer of investigation to provide insights in construct and configurations; collaborations and capabilities; context and change, needed to operate circular business models. This broadens circular business model literature, as this generally only include the description of the circular business model itself.

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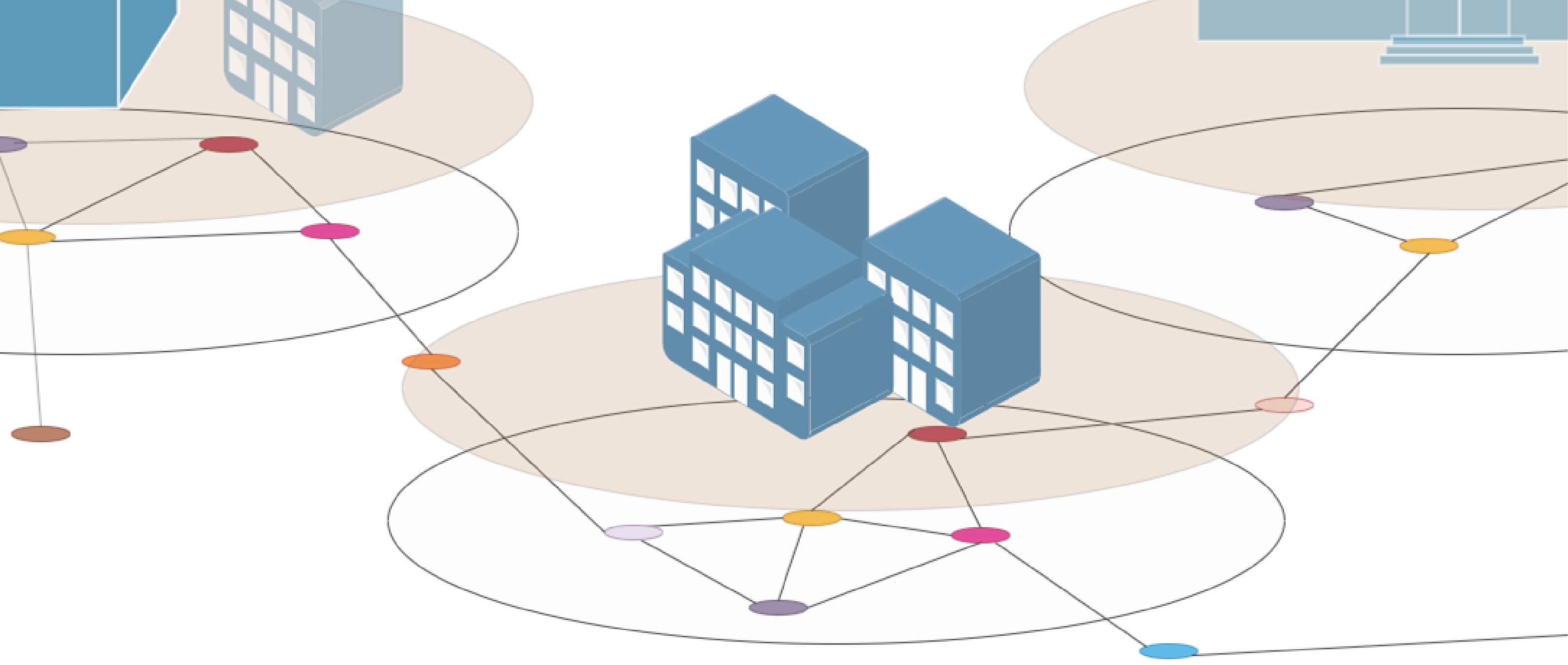


1. Introduction

1. Introduction

In recent years, the concept of Circular Economy (CE) has gained increased attention by scientists and professionals (Centobelli et al., 2020). The basic idea behind the circular economy is the elimination of the concept of waste by rather perceiving waste as a resource (Mahpour, 2018). In the broader field of sustainability, the circular economy is seen as a condition to enhance sustainability. It entails all operations that are aimed at decreasing our resource use and pollutive activities by a better use of waste outputs (Geissdoerfer et al., 2017). Applying circular strategies (e.g. reuse, refurbish, recycle) in practice promises to create cleaner alternatives to primary materials and reduce environmental impact. The principles applied in the circular economy can be summarized as slowing (i.e. extending lifetime), narrowing (i.e. using less materials), closing (i.e. reuse or recycle materials back in to the loop) or regenerating (i.e. use regenerative materials e.g. biobased materials) the loop (Konietzko et al., 2020a).

The concept of the circular economy has inspired governments globally, nationally, and regionally. The European Union (EU) has set the target to become a full circular economy by 2050. The Dutch Government has adopted the ambition to become a full circular economy by 2050. As a sub target the number of primary materials used in the Netherlands should reduced by 50% by the end of 2030 (Rijksoverheid, 2016). One of the key target sectors to create circular material loops is the construction and demolition industry.

In Europe, the construction industry (i.e. housing construction, utility construction and infrastructure) is responsible for 50% of total material extraction (European Commission, 2020) and generates around 35% of the European total waste production (Eurostat, 2016). In the Netherlands, demolition waste from buildings and other constructions consist of 80% stony debris, 15% asphalt and 5% other materials (i.e. wood, gypsum, glass, metals and others) (Kok & Koning, 2019). Asphalt is reused for new road construction and stony debris is mostly used for the backfilling of roads (Kok & Koning, 2019). Only a small part of concrete debris is recycled in new concrete to as a gravel component replacement in concrete. The remaining 5% of C&D waste predominantly consist of wood and metals. Only a small portion of the C&D waste consists of gypsum and glass that needs to be separately collected. On average, 98% of this amount was purposefully that involves reuse, recycling, backfilling and incineration with energy recovery (CBS, 2019). However, strategies like backfilling and incineration with energy recovery do not attribute to a circular economy. In fact, the use of demolition waste as road foundations and embankment is generally perceived as downcycling (Vandecasteele et al., 2013).

Within the built environment, the circular economy can be described as the practice to maintain or enhance value of building materials and components to the largest extent possible by either reuse or recycling (Lemmens & Luebkeman, 2016). In a circular economy, buildings should be regarded as temporary material and product banks that consist of useful materials and products (Ghaffar et al., 2020). To move exploit this potential one should strive towards the highest possible achievement in demolition waste handling. In order to do so, one can apply circular strategies like deconstruction, selective dismantling, material and component reuse and closed-loop recycling to close the loop on building materials in the end-of-life stage of a building (Adams et al., 2017). High value reuse and recycling is achieved when salvaged materials (i.e. materials from old building stock) almost totally substitute their primary counterpart (Ruiz et al., 2020). Since building materials are present in all building lifecycle stages (i.e. from preconstruction to renovation, to end-of-life, to material recovery and secondary material production), the establishment of markets for high value reuse and recycling of building materials require collaborations between multiple C&D actors (Ruiz et al., 2020). In addition, stakeholder collaboration is important to establish circular value chains in the building industry (Adams et al., 2016; Leising et al., 2018).

One could perceive the establishment of these circular value chains also from a business ecosystem perspective. Moore (1993) first introduced the concept of business ecosystems, arguing that companies should rather collaborate than compete to successfully introduce a certain innovation to respond to new trends. Jointly creating an innovation has the advantage that one can make use of each other's capabilities (e.g. knowledge, R&D, logistics). Hsieh et al. (2017) argue that there is a need to link circular economy to business ecosystem research to gather knowledge on how businesses operate a circular business ecosystem successfully to create economic and environmental value simultaneously. A more profound understanding of business ecosystems provides insights on how to build, structure, organize and transform networks in other to capitalize on new trends (Parida & Wincent, 2019).

Actors in the C&D industry need to adapt their supply chains upon new trends of efficiency, energy reductions and waste and resource handling (Ghaffar et al., 2020). Hence, a (circular) business ecosystem perspective could aid providing a comprehensive overview of circular value chains from a more holistic multi-dimensional perspective. For example, Rong et al. (2015) analysis of Internet-of-Things business ecosystems not only perceived the actor construct and configuration of the value chain, but also the embedded context, the cooperation and capabilities required to operate the supply network.

The aim of this study is therefore to provide insights in how high value reuse and recycling of salvaged building materials and components is achieved from a holistic circular business ecosystem perspective. The is assumed to provide an overview of circular value chains present in the built environment and how the ecosystem (has) evolved around the salvaged material supply networks. Besides, applying a circular business ecosystem is expected to reveal valuable insights in what are successors to achieving high value reuse and recycling. This can in turn be helpful to advance circularity in the built environment to accomplish national ambition to become fully circular by 2050.

This leads to the following main research question:

- ***How can high value reuse and recycling of salvaged building materials and components be achieved in the Dutch C&D environment, following a circular business ecosystem perspective?***

And the following sub research questions:

- ***What are the current barriers and enables to achieve high value reuse and recycling in the (Dutch) built environment?***
- ***What is a circular business ecosystem and how can a circular business ecosystem be analyzed?***
- ***How is high value reuse and recycling achieved from a circular business ecosystem perspective in the case of several Dutch demolition contractors?***

The Netherlands is a suitable place to engage this research because of data availability reasons. In the case of the Netherlands, several pilot projects aimed at high value reuse and recycling have already been carried out and published online on websites of companies and knowledge sharing organizations (e.g. www.allesovercirculairslopen.nl) or in sectoral journals (e.g. Cobouw). Thereby, sectoral reports of actors in the built environment pay increased attention to circularity (e.g. Sloopsector, Branchevereniging Nederlandse Architectenbureaus (BNA)).

To answer this question a qualitative research approach is applied. The research flow diagram is found in Figure 1. To answer this research question, the first two sub research questions: '*What is the current state-of-the art literature on high value reuse and recycling in theme (Dutch) built environment?'* and '*What is a circular business ecosystem and how can a circular business ecosystem be analyzed?'* are answered in Chapter 2: '*Literature Review: Barriers and enablers to high value reuse and recycling of building materials & circular (business) ecosystems'*. Secondly, the sub research question. To answer the first sub research question information was retrieved from recent academic articles. To answer the second research question a proper literature review was carried out. To create a definition of a circular business ecosystem, the Google Scholar database was used by entering the following key terms: "circular economy business ecosystem", "circular business ecosystem" and "circular ecosystem". Accordingly, to formulate a starting point for a circular business ecosystem framework the key terms '"circular business ecosystem" framework' and "business ecosystem framework" were used. The selected was tailored to circular business ecosystem analysis by the same literature found to formulate the circular business ecosystem definition. Subsequently, the tailored framework is used to constitute the code scheme and interview protocol used in this study.

To apply the circular business ecosystem perspective, a case study analysis was conducted that involved interviewing four Dutch demolition contractors that are concerned with circularity in the built environment. Demolition contractors experience a difficulty in creating an evident financial and business case for secondary material use in the built environment (Adams et al., 2017). This makes it interesting to see how they have been achieving high value reuse and recycling. Besides, demolition contractors are the secondary material miners in the built environment. Therefore, demolition contractors are the case study actor group as they are expected to initiate or orchestrate firm-boundary spinning ecosystem collaborations to achieve circularity.

To gather meaningful results from the data, a hybrid coding strategy is used as a method to gather meaningful information from the case studies data. The strategy is a combination of a deductive (i.e. using a set of pre-set codes that originates from literature review) and inductive coding strategy (i.e. allow for codes to originate during the coding process). The exact details of the methods applied in this study are found in the Chapter 3: '*Methodology: methods used to analyze empirical data*'.

Then, by coding analysis of the four cases the last sub question is answered: *How is high value reuse and recycling achieved from a demolition contractor perspective?* This involved the analysis of interviews and some secondary data that was added to solve unclarities in the interviews. The results are found in Chapter 4 '*Results: case study analysis of four demolition contractors'.* Subsequently in Chapter 5: '*Discussion: reflections on results'* the meaning, interpretations and implications of the results are discussed. Next to the importance of results, their contribution to academic literature and practical relevance. This chapter also discusses the contribution of practitioners that reflected upon the findings of research for verification. Lastly, the answers to all sub research questions, answer to the main question, outlook, research recommendations and limitations to study are found Chapter 6: *Conclusions: final research conclusions*'.

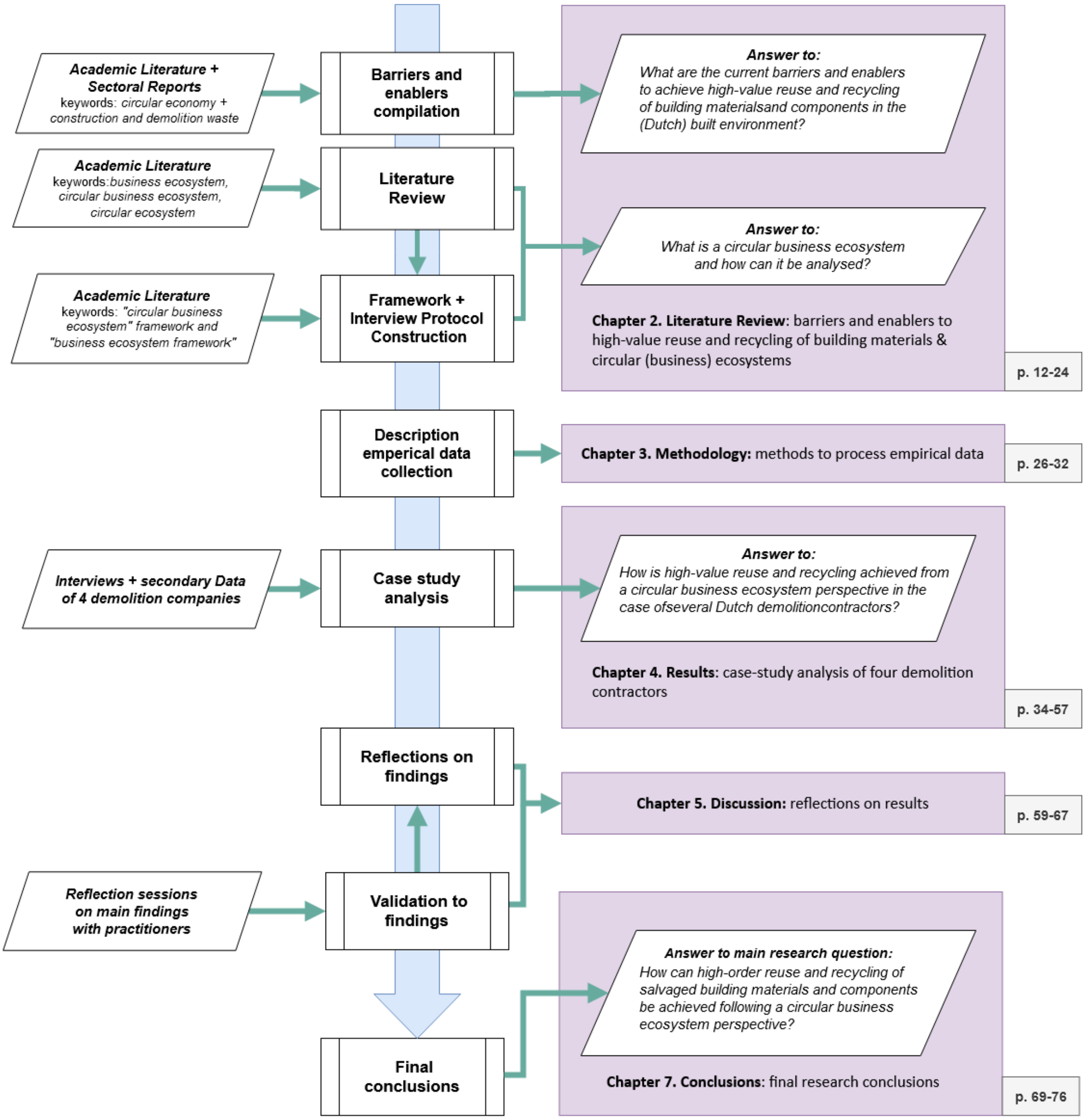
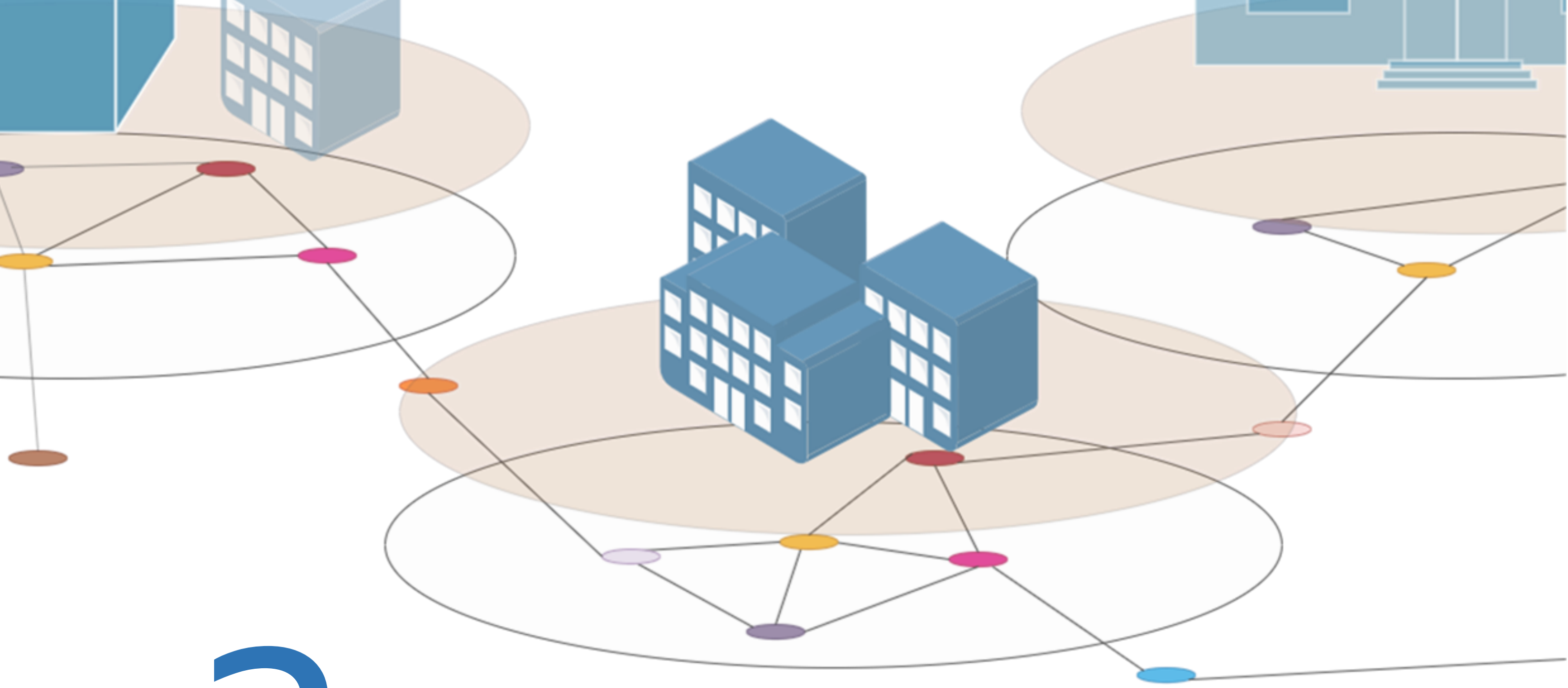


Figure 1. Research Flow Diagram. Left parallelogram shapes are inputs and right parallelogram shapes are outputs. The middle boxes are processes. In this study, first the barriers and enablers are described. Second, a literature review is carried out that is used to formulate a definition of a circular business ecosystem, to retrieve framework elements that describe a circular business ecosystem and to establish the interview protocol used in this study. Third, a case study analysis is conducted from interviews and secondary data. Secondary data is only added in to clarify the interview data. The findings that followed from this research are discussed with relevant experts to validate findings. This group consisted of 1 small architect that designs with circular materials, 3 consultants that have worked on circular building projects and 1 expert that stimulates circular building practices. This input is accounted for in the Discussion chapter. The final conclusions are described in the Conclusion chapter.



2.

Literature Review

Barriers and enablers to high value reuse and recycling of building materials & circular (business) ecosystems

2. **Literature Review**: barriers and enablers to high value reuse and recycling of building materials & circular (business) ecosystems

This chapter starts by explaining the barriers and enablers to high value reuse and recycling of salvaged materials. Salvaged materials are those materials that are immediately retrieved from old building stock by dismantling. Dismantling is the practice of carefully demolishing old building stock to retrieve useful salvaged materials and components (e.g. for further reuse, recycling or refurbishment). Most information is gathered from recent academic articles about circular (construction and) demolition waste handling. Additional report data about the Dutch demolition industry is used to describe and link academic information to Dutch practice. This chapter further stresses the need for a new ecosystem perspective to elaborate on how high value reuse and recycling of salvaged materials can be achieved. Subsequently, an explanation of the circular business ecosystem is provided, as well as a framework to analyze circular business ecosystems.

2.1. Bottlenecks in high value reuse and recycling of salvaged building materials

2.1.1. The retrieval and adaption of salvaged materials is costly and time-consuming

Currently, secondary materials must compete with low priced virgin materials (Migliore et al., 2020, p.68). In that respect, high value reuse or recycling is not always economically interesting as **high value recovery does not always cover the additional costs** for dismantling and refurbishment (Kok & Koning, 2019). Costs could certainly be a bottleneck for high value reuse and recycling of C&D waste and make low-value options, like backfilling, more economically preferable (Ghaffar et al., 2020). Generally, some elements and components retrieved from old buildings will **require adaptation** (e.g. refurbishment and repair) **to fulfill new building requirements**, when reused in the built environment. For example, in case measurements of the retrieved components of old buildings do not fit the new building requirements (Kok & Koning, 2019). This results in additional labor costs for refurbishment. Also, retrieving the materials and components in a proper way (e.g. by certain **selective demolition techniques** or adequate separation processes) for reuse and recycling **demands more time** (Ghaffar et al., 2020). From a cost-perspective, **logistics** can also be a setback (Ghaffar et al., 2020). Also from an environmental perspective, as the **environmental benefits of high value reuse and recycling are highly influenced by transport distance and type of transport** (Ruiz et al., 2020).

2.1.2. The lack of information on material characteristics

In addition, Information on quantities and quality and conditions of building materials need to be present to effectively implement circular economy strategies in buildings (Ghisellini et al., 2018). **The number and specifics of the materials inside the building are generally not known** (Migliore et al., 2020, p.69). Acquiring information about the **material composition and in-use lifetime may be unavailable and require testing, which can increase the costs of recovery** (Ghaffar et al., 2020).

2.1.3. The process of matching material supply to demand

Additionally, demolition contractors **need clients for salvaged materials**. Albers, Luijten & Van Dinther (2019) provide information on a Dutch circular demolition case in which all demolition contractors made different offers, because all had different networks of customers. However, these networks do not guarantee demand. Salvaged materials **also need to be competitive in quality and quantities** (Ghaffar et al., 2020). There can be a **mismatch of supply and demand in salvaged building materials**, which is considered as a problem amount Dutch demolition contractors (Kok & Koning, 2019). This hampers fulfilling current demand, as well as the business case. In case temporary **off-site storage** is needed to meet demand that can increase costs (Gorgolewski, 2008).

2.1.4. Legislations and standards

Ghaffar et al. (2020) found **that hygiene and safety regulations can be a setback for high value reuse and recycling**. In the Dutch demolition sector, regulatory frameworks are currently found not very suitable to high value reuse. For example, it is difficult for salvaged materials to fulfill current obligatory building and quality requirements and energy standards (Kok & Koning, 2019).

2.2. Enablers to high value reuse and recycling of salvaged building materials

2.2.1. Optimizations in different stages of the building's life cycle to minimize C&D waste

As enablers, Ruiz et al. (2020) mention several optimizations in different stages of the building's life cycle to minimize C&D waste. Ruiz et al. (2020) divided the building's life cycle stages in: *preconstruction*, *construction and renovation*, *collection and distribution* of C&D waste (this include waste-streams from both *end-of-life* and *construction and renovation*), *end-of-life* and *material recovery and production*. The building should be designed to minimize waste and maximize second-life building material use in the later life-cycle stages. For example, in preconstruction stage, policies and regulatory frameworks should support the prioritization of proper C&D waste recovery and secondary materials use in construction projects (Ruiz et al., 2020). Besides, including C&D waste management plans for later life-cycle stages, enhances opportunities cleaner C&D waste fractions in the *collection and distribution* (Ruiz et al., 2020). *Collection and distribution* of C&D waste should be characterized by a focus on high value reuse and recycling of the salvaged building materials. On-site sorting activities are preferred as they create less environmental impact due to less logistics needed. The salvaged materials can be repurposed via brokerage by a marketplace or by take-back schemes supported by suppliers of short-lived products (Leising et al., 2018). **Selective deconstruction (or dismantling)** followed by proper collection and segregation maximize material recovery in the end-of-life stage (Ruiz et al., 2020). In addition, **pre-demolition site assessments or audits** can be used to inventory building material and components that have a high potential for reuse, recycling, and subsequent reselling (Ghaffar et al., 2020).

2.2.2. Support of environmental impact calculation tools

Environmental impact calculation can help to demonstrate the difference in environmental impacts between secondary and primary materials. In the Netherlands, on governmental level the MPG (abbreviation of: MilieuPrestatie Gebouwen) is used as an environmental performance indicator for buildings. The working principle behind the MPG is that a better prestation is achieved using sustainable building materials. The calculation of the MPG is based on lifecycle-assessment (LCA) calculations of the materials used. Besides, also certification schemes for the sustainability of C&D projects are available, like BREEAM-NL. BREEAM-NL has four certifications: area, renovation and new construction, in-use, demolition, and disassembly.

2.2.3. Governmental incentives and legislation

Ruiz et al. (2020) mention that proper legislation and regulatory frameworks are needed to provide guidance for improving C&D waste management, but also to support secondary material production. In this regard, Schraven et al. (2019) found that governmental incentives (e.g. funding and legislation) stimulates recyclers to innovate their business operations in the stony material supply chain in the Netherlands. Another example is landfill bans on reusable construction and demolition waste (Ruiz et al., 2020). In turn, demolition contractors must find higher value ways to deal with demolition waste.

Recently, the European Commission (EC) has constructed a Circular Economy Action Plan in which the category *constructions and buildings* is identified as a key area that needs improvement on waste handling in accordance to circular economy principles (European Commission, 2020). To accelerate this transition the EC funds European circular initiatives in the built environment (e.g. Building as Material Banks (BAMB, 2020) and the EU Research and Innovation program Horizon 2020 (EC, 2017).

Besides, the Dutch government has set national subgoals on circularity in the built environment. For example, the Dutch government' building portfolio of offices and infrastructure should be maintained fully circular by 2030 (Rijksoverheid, 2019, p.42). Besides, Dutch governmental bodies require quality criteria on circular material use in their tenders, setting an example to the market. Besides, the government set ambitions to realize 100% high value reuse of concrete debris (Rijksoverheid, 2019, p.42). In alignment with this ambition, several vast C&D actors have signed the "Concrete Agreement"; a voluntary agreement of actors in the stony supply chain about achieving high value recycling of concrete in 2018 (Betonakkoord, 2018). Following the ambitions of the Betonakkoord, all concrete C&D waste streams should be used to create 100% recycled concrete. Lastly, the government is also exploring how material passports could attribute to circular design and application of circular building materials (Rijksoverheid, 2019, p.38).

2.2.4. More cross-industry collaboration in circular projects and value chains

Leising et al. (2018) recommend starting circular construction projects with clear circular vision and ambitions, executed by a multidisciplinary team. Part of the collaboration is characterized by non-traditional contracting, trust and making use of building integrated modelling (BIM) and material passports to track material use and value (Leising et al., 2018). Besides, they recommend including a system scan for value creation for all stakeholders involved. For developing circular value chains in the building industry stakeholder collaboration is also seen as very important (Adams et al., 2016; Leising et al., 2018). According to Debacker et al. (2017) moving towards a circular built environment involves more collaboration throughout the value network.

2.3. An ecosystem perspective to reuse and recycling of salvaged materials

To sum up, from literature follow that high value reuse and recycling of salvaged building materials is not easily achieved. Secondary building materials must compete with their primary counterparts, that are relatively inexpensive (Migliore et al., 2020. p.68). Components can require adaptation, like refurbishment and repair, that enhance the costs. Besides, Ghaffar et al. (2020) mention the practice of dismantling is more time-consuming, requires logistics and even sometimes additional material testing. Also, reuse or refurbishment of components may be technical feasible, but have high environmental costs due to transport (Ruiz et al., 2020).

Ghaffar et al. (2020) also mentions that secondary products not only need to be cost competitive to new alternatives, but also competitive in quality and quantities. In quality, secondary building materials must comply with hygiene and safety regulations. They also may not be suitable because they do not meet current building requirement and energy standards (Kok & Koning, 2019). In quantity, there can be a mismatch supply and demand. This can also lead to costs for off-site intermediate storage (Gorgolewski, 2008).

Regarding enablers, several circular optimizations in different stages of the building's life cycle are needed. Environmental impact calculations can support sustainable decision-making. Besides, governmental incentives and legislation can support high value reuse and recycling (Ruiz et al., 2020). Lastly, more collaboration between actors in the C&D industry is important to establish circularity in the built environment (Adams et al., 2016; Leising et al., 2018).

Hence, several authors have proposed ways to improve circularity in the C&D by recovering materials form old buildings stock. However, no authors are explicit on what actors, cooperation and capabilities are needed to establish these a circular value chains. A circular business ecosystem perspective is expected to offer these insights.

2.4. Defining a circular business ecosystem

The keywords used to retrieve information for defining a circular business ecosystem are: "circular economy business ecosystem", "circular business ecosystem" and "circular ecosystem". Google Scholar was retrieved as database. Further specifications on the data collection procedure for this literature review (e.g. number of results and selected articles) are explained in Appendix A2 and A3. For extra clarification on the circular economy concept and circularity in the built environment see Appendix A1.

2.4.1. Ecosystem thinking in business (model) literature

Konietzko et al. (2020a) argue that a company should not only focus on the product or service circular business model, but also on the ecosystem of actors that surround the business model. For example, if a clothing manufacturing company wants to make use of recycled material of their own produced clothing, this probably needs collaboration with recycling companies to create circular material loops. These ecosystem actors generally need to change their practice as well (Konietzko et al., 2020a). For example in the case of clothing, the recycling company may create a new recycling process and customers need to bring their old clothes to a collection point. The ecosystem can become a means to establish strategic relationships with all (new) value chain actors to improve the circularity in every lifecycle stage (Lacy et al., 2020, p.284).

The idea of perceiving strategic cooperation between businesses (and other actors) as ecosystems, sprouts from the mechanics of the evolvement of natural ecosystems. For example, surrounding conditions impact the species composition in the natural ecosystem. Moore (1993) introduced the concept of business ecosystem by arguing that this would better explain the emergence of inter-firm collaborations to introduce new innovations. Cooperation and competition are key elements of a business ecosystem aimed at creating capabilities to bring about the innovation in question and work towards a shared future (Moore, 1993). A characteristic of a business ecosystem is that it encompasses multiple industries that are either part of the supply network or customer segments (Moore, 1993). These actors not only include businesses, but also academic institutions, stakeholders, associations, and other organizations (Moore, 1996). The field of business ecosystem research further developed by research on the evolvement of a business ecosystems in terms of its stakeholders and their roles and interactions and how these are related to value capture (Rong et al., 2015). As a matter of definition, a business ecosystem can be described as "*a set of actors - producers, suppliers, service providers, end users, regulators, civil society organizations - that contribute to a collective outcome*" (Konietzko et al., 2020a, p.253).

2.4.2. Recent literature on business ecosystems in the circular economy

Recently, several authors have linked business ecosystem thinking to the circular economy. For example, Hsieh et al. (2017) applied a business ecosystem perspective to study a Taiwanese Recycling leader. More recent, Tate et al. (2019) connected natural ecosystem research to business ecosystems and identified six biomimetic principles that occurred in business ecosystems that conduct circular operations. Parida & Wincent (2019) argue that applying an ecosystem perspective can help to generate insight in how trends as the circular economy are implemented. Parida et al. (2019) derived ecosystem orchestration mechanisms from case study analysis on manufacturing companies. Gupta et al. (2019) notes that businesses should be holistically regarded as part of an ecosystem compiled of multiple stakeholders that collaborate whilst having a united vision and sustainability goals. Zucchella (2019b, p.184) describes that an ecosystem in a circular economy entails the structure of stakeholder' relationships that supports the implementation of circular economy business models. Lacy et al. (2020, p.284) mentions that collaboration with other partners is needed to accomplish a circular economy business case. It for example, often requires setting up different supply chains and infrastructures e.g. take-back infrastructure. Cramer (2020) mentions a circular ecosystem in the context of describing a network of actors (e.g. businesses and citizens) surrounding a circular initiative. Lastly, Konietzko et al. (2020a) defined initial principles of circular ecosystems.

2.4.3. A definition of a circular business ecosystem

Throughout the literature review, the concept of "circular business ecosystem" and "circular ecosystem" - if named by authors - were generally used to describe the same: companies (and other actors e.g. government) that work together towards integrating circular economy principles in their business operations. However, in none of these articles and book chapters an exact circular business ecosystem definition was found, though definitions of circular (economy) ecosystems were given. For example, Lacy et al. (2020) described a circular ecosystem as " *the network of organizations collaborating and partnering to create an enabling environment for collective transformation—making it possible for entire value chains (or for particular regions, e.g., a city or an operational zone) to shift from linear to circular ways of doing business*" (Lacy et al., 2020, p. 283-284).

Besides, Konietzko et al. (2020b) defined characteristics of circular ecosystems:

a. A circular ecosystem is compelled of several geographically spread entities that are not part of one organization
b. A circular ecosystem involves changing, cooperative and competing relationships
c. A circular ecosystem encompasses services, capital and data flows
d. A circular ecosystem generally concerns complementary products, services, and capabilities to enhance circularity
e. A circular ecosystem continuously emerges since ecosystem actors keep reconfiguring their relationships and capabilities

Building on the findings from this literature review, a circular business ecosystem is defined as '*a set of actors that jointly work towards achieving the collective outcome of closing, narrowing, slowing or generating the loop on resources establish a circular innovation (e.g. product or service), initiative or project*'. Figure 2 displays this definition. Accordingly, characteristics of circular business ecosystems are the application of circular economy strategies and circular economy business models. Value is created from narrowing, slowing, closing, or regenerating the resources loop.

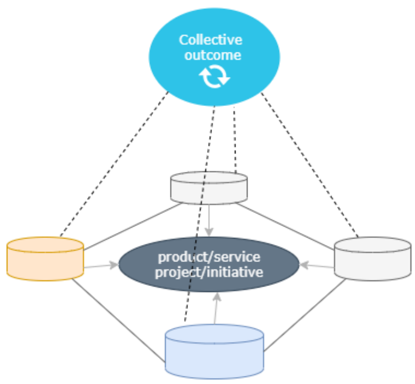


Figure 2. Image of the circular business ecosystem definition: multiple actors of different types work together to create a circular innovation (e.g. product or service), project, or initiative, all adhering the collective outcome to narrow, slow, close, or regenerate the resources loop.

2.5. A framework to analyze a circular business ecosystem

To select a framework for analyzing circular business ecosystems the Google Scholar database was used by entering the following key term: "circular business ecosystem" framework. This resulted in only 12 results. Most of the results concerned circular fashion industries, but these did not provide a framework. Further within these results, a master thesis was found that contained an economic analysis on limestone processing. Herein, no circular business ecosystem framework was found either. Hence, to formulate a starting point for a circular business ecosystem framework, the key term "business ecosystem framework" was used in Google Scholar. The second hit was the 6C-framework of Rong et al. (2015) describing the 6C-framework for analyzing Internet of Things (IoT) business ecosystems. After screening the first 20 out of 100 results, this framework was found the most useful as it was the most recent, elaborated and structured framework to describe a business ecosystem. Rong et al. (2015) recommended further application of the 6C-framework to other disciplines but stressed potential difficulties for application to other business ecosystems. Therefore, the 6C-framework is tailored and adapted to the purpose of this inquiry to analyze circular business ecosystems.

2.5.1. The 6C-framework

The 6C-framework evolved from global supply chain management literature and was used by Rong et al. (2015) to analyze the IoT-business ecosystems. These six dimensions are **context** (i.e. environmental characteristics of the supply network), **construct** (i.e. infrastructure and structure of business ecosystem), **configuration** (i.e. partners in supply network and how these form configuration patterns), **cooperation** (i.e. collaboration and governance mechanism of the ecosystem), **capability** (i.e. key success features of the ecosystem) and lastly **change** (i.e. how a business ecosystem can shift from one configuration to another). Rong et al. (2015) derived certain explanatory categories for the 6C-dimensions. The 6C-dimensions and their subcategories are displayed in Table 1. In the following sections the 6C-dimensions are tailored to business ecosystem literature. The supportive literature to do so, is the same literature on circular (business) ecosystems that was used to form the circular business definition. Appendix B contains a literature map that displays how the circular (business) ecosystem literature is connected to the 6C-dimensions.

Table 1. Definitions of the 6C and their categories by Rong et al. (2015)

Dimension	Subcategories of the dimensions, by Rong et al. (2015)
Context *describes the environmental features of the supply network*	1. Life Cycle Stages 2. Drivers 3. Barriers 4. Missions
Construct *describes infrastructure and structure of business ecosystem*	1. Structure 2. Infrastructure
Configuration *describes the operational mechanisms in supply network and how these form configuration patterns*	1. Pattern 2. External Relationship
Cooperation *describes the collaboration and governance mechanisms of the ecosystem.*	1. Coordination Mechanism 2. Governance System
Capability *describes the key success features of the ecosystem*	1. Communication & Accessibility 2. Integration & Synergy 3. Learning Adaptability 4. Adoption & Mobility
Change *describes the process of shifting from one business ecosystem configuration pattern to another*	1. Renewal 2. Co-evolution

2.5.1.1. Context

Rong et al. (2015) define the Context dimension of their framework as the category that analyses how the supply network emerges. The context dimension describes the key *barriers*, *missions*, and *drivers* of the emergence of the ecosystem (Rong et al., 2015). Moore (1993) distinguished the development of an ecosystem into four stages: birth, emergence, leadership, and self-renewal. In the context of business ecosystems that specifically work towards circularity, these life cycles can be distinguished in four stages: emerging, established, leading and ultimate (Lacy et al., 2020, p.284).

Regarding drivers to create a circular (business) ecosystem, these can be **a changing external environment** (e.g. social pressures, climate change, policies) and/or **resource scarcity** (Parida & Wincent, 2019). This may require the business to operate differently and demands a reconsideration and reconfiguration of relationships and collaborations to do so (Parida & Wincent, 2019). **Solving market failures** can be regarded as business opportunities to reduce environmentally harmful operations (Zucchella,2019b, p.139). From a supply chain perspective, **enhanced profitability, cost efficiencies** and **better customer offerings** are reasons to engage in an ecosystem (Gupta et al., 2019). Regarding barriers, **regulations** can impose barriers to adopt circular practices (Lacy et al., 2020, p. 295).

A possible **mission** of a business ecosystem in a circular economy is creating **more scale** (Lacy et al., 2020, p.284) and/or accomplishing **environmental targets** (Parida et al., 2019). **Clear goals and routes** and how to achieve collective outcomes are important guidance to clear role division in the ecosystem (Konietzko et al., 2020a). Furthermore, a **mutual goal** is essential for a business ecosystem (Moore, 1993). From a natural ecosystem perspective, the mutual goal of an ecosystem is **increasing the overall efficiency of the system to eliminate waste** (Tate et al., 2019).

2.5.1.2. Construct

The construct of a business ecosystem encompasses the supportive infrastructure and structure of the ecosystem. To explain these, Rong et al. (2015) used a "structure-infrastructure" lens from manufacturing management and supply chain theories. This lens seems too manufacturing specific for describing the construct, since a circular business ecosystem can also concern projects or initiatives.

Tate et al. (2019) refer to the **actor balance** as the balance of actors' roles that is present in natural ecosystems. A circular business ecosystem is compiled of heterogeneous actors and actor' roles since there are not only **producers** and **consumers**, but also decomposers and scavengers (Tate et al., 2019). **Scavengers** are ecosystem actors that are responsible for the dismantling, sorting, and transportation of secondary materials. **Decomposers** are ecosystem actors that transform or adapt secondary materials to reuse them back into the ecosystem (Tate et al., 2019). The ecosystem can also include non-business actors as (non-)governmental organizations and scholars (Lacy et al., 2020, p.286).

Parida et al. (2019) & Parida & Wincent (2019) define the initiating party of an ecosystem as an **ecosystem orchestrator**. The ecosystem orchestrator jointly creates value with other actors in the ecosystem (Parida & Wincent ,2019). In the case study of Cramer (2020) on closing the loop on nine resources streams in the Amsterdam Metropolitan Area, the Amsterdam Economic Board (AMEC) had an initiating role. AMEC facilitated the creation of circular actor coalitions (Cramer, 2020). So, in these cases, a **facilitator** is the initiating party. Lastly, Parida et al. (2019) mention a **mediator** or **moderator** that can orchestrate a circular business ecosystem.

Circular business ecosystems are often also supported by a virtual infrastructure (Tate et al., 2019). **Integrated material and information flows** and **decentralized storage** are often found important to establish circularity (Tate et al., 2019). According to Konietzko et al. (2020a) data flows are particularly important in a circular ecosystem because they offer possibilities to optimize the use of products and materials and to create insight in value creation opportunities. As they formulate it: "*Data flows enable better information access on the use, condition and location of the ecosystem assets and thus contribute to a more efficient management of their usage and circularity*" (Konietzko et al., 2020a, p.10). Tate et al. (2019) also mention the potential of **transparency on material information data** to estimate the value of materials for potential take back and material recovery options. In this regard, Big Data analysis potential to optimize circular business operations (Gupta et al., 2019)**.** Alexandris et al. (2018) propose a Blockchain technology in which all Lifecycle Assessment properties (e.g. **availability, condition, and location**) of the asset are stored. Blockchain technology offers the possibility "*to create a permanent, shareable, actionable record of every moment of a product's trip through its supply chain thus providing seamless product traceability, authenticity and legitimacy*" (Wang et al., 2019, p. 62). Data management (e.g. data acquisition, retrieval, storage, and analysis) can be used for effective decision-making to enhance operations (Gupta et al., 2019). Lastly, the **virtual infrastructure** can consist of a digital platform where physical assets are offered (Konietzko et al., 2020a). **Digital platforms** can also be a means to distribute knowledge, insights and capability sharing (Lacy et al., 2020, p.297).

2.5.1.3. Configuration

In the dimension Configuration, Rong et al. (2015) explore the operational mechanisms in supply network and how these form configuration patterns. To gather information on external relationships and patterns Rong et al. (2015) asked in their interview protocol for the business process and business models applied.

Regarding the business process, Gupta et al. (2019) draws a parallel between supply chain management and the circular economy, because both need **effective business process management**. In this regard, Cramer (2020) mentions **agreements on preconditions** as a necessity to a well-functioning circular supply network. Examples of these preconditions are suitable collection and logistics, waste volume guarantees, pre-set recycled material demand and certain material quality standards.

Business models are an important part of mapping the minimum viable circular ecosystem as it provides insight in the viable ecosystem configurations (Konietzko et al., 2020b). In a circular business ecosystem, all ecosystem actors - customers, manufactures, regional distributors, and suppliers – all take part in the transformation to different business models (Parida et al., 2019). In a business ecosystem all actor' business models are equally important (Konietzko et al., 2020b). In circular ecosystems, additional value can also be created in terms of **social benefits** and **environmental gains** (Lacy et al., 2020, p.289; Parida et al., 2019). Circular economy business models are focused on retaining product, component and/or material value (Lüdeke-Freund et al., 2019). Lüdeke-Freund et al. (2019) distinguishes six patterns in circular economy business models: refurbishment & remanufacturing, recycling, repair & maintenance, reuse & redistribution, cascading & repurposing, or organic feedstock production.

Cramer (2020) found that most consortia that surrounded a circular initiative on closing the loop on material flows in the Amsterdam Metropolitan Area applied **a shared costs and profit** model. This model implies that each actor retrieves a proportional profit share. This model secured financial attractiveness of the circular initiative to all ecosystem partners. Konietzko et al. (2020a) found that **fair value capture** among actors is needed to establish trust and to assure commitment to deliver the promised contributions in time.

2.5.1.4. Cooperation

Cooperation describes the interaction mechanisms and relationships in the business ecosystem (Rong et al., 2015). To describe the structural complexity of relationships, Tate et al. (2019) used a description of **the density of the network, network complexity** and **interdependency**. According to Tate et al. (2019) a circular business ecosystem is characterized by a dense network of heterogeneous ecosystem actors with multiple interconnections. Regarding interdependency, Parida et al. (2019) mention **risk division** and **granted exclusivity** as strategies to influence relational independency between ecosystem actors. Risk division concerns negotiating different revenue and risk arrangements. **Granted exclusivity** is another way to create dependency amongst ecosystem actors. For example, Parida et al. (2019) found that in a circular business ecosystem some smaller companies were hesitant to make investments in circular economy solutions since they were regarded as high cost investments with uncertain returns to the company. In that case, ecosystem actors can provide exclusivity agreements to other ecosystem actors (e.g. actor supplies exclusively goods to other actors) to reach the collective outcome of the ecosystem (Parida et al., 2019).

Parida et al. (2019) found that the governance mechanisms of ecosystem orchestrators are **negotiation, nurturing,** and **standardization**. **Negotiation mechanisms** concern new partner inclusion strategies to upscale circular operations. Reasons for **new partner inclusion** are for example finding partners with competencies that are needed in the ecosystem or to scale-up the market (Parida et al., 2019). Parida et al. (2019) found **give and take rules**, **relational interdependence** (e.g. profit sharing and purchasing arrangements, granted exclusivity, risk division) and executing a **risk-benefit analysis** and as negotiation mechanisms to partner inclusion. For example, **give-and-take relationships** are there to assure core ecosystem actors' interests in joining the ecosystem (Parida et al., 2019).

Standardization are mechanisms through which ecosystem actors can accomplish circular economy targets (Parida et al., 2019). Parida et al. (2019) found that ecosystem orchestrators formulate specific standards with certain ecosystem actors and create broader standards for a wider set of ecosystem actors. Parida et al. (2019) found three **standardization mechanisms** from their case study research: promoting industry-wide standards, co-developing technological standards and setting up informal and formal certification schemes. **Technological standard co-development** by ecosystem actors was found important for assuring commitment to certain environmental quality goals for product parts (Parida et al., 2019). Lastly, **informal standardization** was used to create the ecosystem's architecture, but **formal certification** of new circular economy technologies or concepts was found to be important to gain a wider acceptance amongst ecosystem actors (Parida et al., 2019).

Nurturing mechanisms are for example providing direct **early investment** by the ecosystem orchestrator to other ecosystem actors and granting support to capability development, knowledge sharing and intellectual property to achieve the collective outcome (e.g. circular economy targets) (Parida et al., 2019).

2.5.1.5. Capabilities

Rong et al. (2015) describe the Capabilities dimension as the key success features of the ecosystem. Capabilities are essential to success for an organization to keep up with trends like circular economy, digitalization and offering products as a service (Parida & Wincent, 2019). Actors can make advantage of each other capabilities in a circular business ecosystem. Rong et al. (2015) mention communications and sharing, learning and innovation, integration and synergizing and adaptation and restructuring as capabilities to the business ecosystem. They for example found R&D capabilities, customer engagement, platform openness and innovation capabilities as important capabilities to certain IoT-business ecosystems. A circular business ecosystem requires capabilities that are aligned with collective outcome of closing, narrowing, slowing, or regenerating the loop. However, since no research is available on the possible capabilities of a circular business ecosystem, the capabilities categories of Rong et al. (2015) are tailored to a circular business ecosystem perspective.

Regarding integration and synergizing, **supply chain integration** can be useful for optimization in a circular business ecosystem (Gupta et al., 2019). Also, **services integration** across ecosystem actors may be helpful to generate most environmental benefits and highest customer value (Parida & Wincent, 2019). On the governance level of circular ecosystems, Konietzko et al. (2020a) also found that a **shared vision** can be a great basis to **align individual and shared interests.** In an ecosystem the ecosystem leader orchestrates its business operations with a shared vision on what value should be created for whom (Parida & Wincent, 2019). The **development of common strategies and goals** is important to develop a common language, create a goal and strategies alignment and a shared feeling that the innovation can really succeed (Konietzko et al., 2020a). According to Konietzko et al. (2020a) common strategies and goals can only be created and accomplished by undertaking joint activities.

In relation to innovation and learning, Tate et al. (2019) mention the need to find ecosystem actors with **complementary capabilities** that can work **jointly** to solve **problems** (e.g. the breakdown of a complex product to its materials). The different ecosystem actors will bring their own problem-solving approach that lead to new angles to tackle an occurring problem (Konietzko et al., 2020a). This can also involve **co-creation** between ecosystem partners (and customers) to solve circularity problems (Lacy et al., 2020, p.287) and exploit sustainability gains together (Parida & Wincent, 2019).

With respect to **communication and sharing,** the importance of data, knowledge and information sharing can be mentioned (Konietzko et al., 2020a; Tate et al., 2019; Parida et al., 2019). For example, Parida et al. (2019) found that **sharing business information** (e.g. intellectual property) and core **knowledge** are needed to nurture the circular business ecosystem. For example, **customer information** of other business ecosystem actors can be essential to understanding the customer needs for a product or service related to the circular economy (Parida et al., 2019). Also, the effectiveness of collaboration in circular ecosystems is highly due to **capabilities** and **knowledge** distribution (Lacy et al., 2020, p.289).

About **adaptation and restructuring**, business and customers should change their **behavior towards waste** (Zucchella, 2019b, p.198). Tate et al. (2019) found in one case study that a mindset change was needed on how waste is perceived, as the quality of waste materials are not necessarily of less than primary materials. Additionally, Konietzko et al. (2020a) mention the importance of **customer commitment**. Also, **investment commitment** is needed. This involves steering shareholders and investors towards decision-making that is not solely based on the business value, but on other (social and environmental) value creations as well (Lacy et al., 2020, p.295).

In addition, establishing and maintaining **trust** is regarded as an essential element in a circular ecosystem (Konietzko et al., 2020a). Ecosystem partner collaboration needs a higher level of openness and trust (Lacy et al., 2020, p.284). Zucchella (2019a, p.69) also mention trusted relationships as a precondition to success. Mutual trust of ecosystem actors is for example essential to share information and data (Gupta et al., 2019). In addition to trust, Cramer (2020) found that **cohesion** between ecosystem partners in a circular initiative was important to create a pleasant workflow.

2.5.1.6. Change

Rong et al. (2015) describe the Change dimension as the process of shifting from one business ecosystem configuration pattern to another. The formation of an ecosystem is dynamic as it involves co-evolution of ecosystem actors (Rong et al., 2015; Tate et al., 2019). By analogy, a natural ecosystem is a result of years of trial-and-error and still evolves by adaptation to its surroundings (Tate et al., 2019). Business ecosystems can be helpful to capitalize on new trends, like the circular economy (Parida & Wincent, 2019). Parida et al. (2019) argue that transforming or innovating towards circular economy business models require new ecosystem configurations. Subsequently, to create a circular business ecosystem with a broader network of actors and active involvement, a possible reconfiguration of existing collaboration is required (e.g. replacing raw material suppliers for secondary raw material suppliers). In a new or transformed ecosystem that works towards new goals, some new actor' roles need to be introduced or redefined.

Parida et al. (2019) mention strategic and competitive advantages as benefits for operating in an ecosystem. Examples of **strategic advantages** are **less dangerous jobs, greater transparency between ecosystem actors, differentiation of product offerings, differentiation, and cost leadership** (Parida et al., 2019). **Differentiation** is the advantage that within an ecosystem, one can make use of other ecosystem actor capabilities and develop a niche innovation, meanwhile producing the same core products (Parida & Wincent, 2019). Besides, being a pioneer and sharing these experiences with policymakers can **shape the direction setting of regulations.** In this way, the ecosystem collaboration induces a supportive economic environment and **minimizes risk to future (changes in) regulations** (Lacy et al., 2020, p.291).

Examples of **competitive advantages** of operating in a business ecosystem are **higher productivity, better resource use** and **market growth** (Parida et al., 2019). This can result in cost reductions and additional revenue generation (e.g. the use of waste materials for products leads to value creation and capture of an initial 'no value' materials). Another **competitive advantage** is **branding**, since ecosystem actors can signal their leadership and commitment to customers, investors, media, and future employees (Lacy et al., 2020, p.291). Besides, there are mutual benefits like sharing costs and profits, as mentioned earlier by Cramer (2020).

2.6. 6C-framework to analyze a circular business ecosystem

A circular business ecosystem can be explored through the Rong et al. (2015) framework with 6C-dimensions (i.e. context, construct, configuration, cooperation, capabilities and change) tailored to circular business ecosystem literature. This resulted in the adaptations described in Table 2. The following text describes the adapted dimensions to analyze a circular business ecosystem, based on the previous literature review.

In a circular business ecosystem, the **Context** dimension can be best described as environmental features of the circular supply network. It describes the life cycle stages of the ecosystem, the drivers, barriers, and missions. Another feature of circular business ecosystem is the existence of mutual goal to preserve the value of materials over the product's lifecycle. From literature follows that motivations to initiate or participate in a circular business ecosystem are a changing external environment, the urge to solve market failures, resource scarcity and/or create enhanced profitability, cost efficiencies and better customer offerings. Regarding barriers, **regulations** can hamper circular practices (Lacy et al., 2020, p. 295).

The **Construct** dimension entails infrastructure and structure or the constructive elements of the circular business ecosystem. The main actors and their roles comprise the structure of the circular supply network. A circular supply network involves actors that fulfill circular activities, like scavengers and recyclers (Tate et al., 2019). But also involve initiators (i.e. those who orchestrate/set-up the ecosystem or mediators (i.e. those who guide ecosystem developments) (Parida et al., 2019). The Construct dimension is composed of a virtual (e.g. data management, online platforms) and a physical infrastructure (e.g. logistics) that both support the circular supply network. Data management was found helpful by several authors to manage material flows in the ecosystem (e.g. by collects, tracking and storing material data) and exploit value creation opportunities.

The **Configuration** dimension describes all activities in circular supply network and how these form configuration patterns. The composition of this dimension differs from Rong et al. (2015). Therefore, the business model and the process are used to describe this dimension. Business models applied in circular economy ecosystems apply circular economy strategies that relate to retaining product/component value or material (Lüdeke-Freund et al., 2019). In circular business ecosystems one can expect social and environmental benefits as additional value creation to economic value. Value is shared fairly amongst ecosystem actors (Konietzko et al., 2020a). The value created in the ecosystem can also include social and environmental gains (Lacy et al., 2020, p.289). The business process describes all business operations executed by ecosystem actors to obtain the collective outcome of closing, narrowing, slowing or regenerating the loop on resources. Effective process management and a set of preconditions in business operations can help operations to succeed.

The **Cooperation** dimension describes all collaborations and governance mechanisms of the circular business ecosystem. The Cooperation dimension is compiled of network characteristics and govern mechanisms, which differs from the framework of Rong et al. (2015). Tate et al. (2019) describes eminent network characteristics of a circular business ecosystem. According to Tate et al. (2019) a circular business ecosystem is characterized by a dense network of heterogeneous ecosystem actors with multiple interconnections. There can be relational independence in the form of profit sharing, purchasing agreements, granted exclusivity and risk division (Parida et al., 2019). Parida et al. (2019) describes several mechanisms on how the ecosystem is nurtured, maintained, and expanded; and hence governed. This suits governance mechanism better than the initial governance system of Rong et al. (2015). The ecosystem is for example nurtured by actively searching for opportunities for (in)formal standardizations (e.g. industry certificates) and by early-investments and knowledge/IP sharing by the ecosystem initiator or orchestrator (Parida et al., 2019).

The **Capabilities** dimension entails the key success features (or capabilities) used in the circular business ecosystem. The categories that could be compiled from the literature review differ somewhat from those of Rong et al. (2015). The first one, Integration & Synergizing is based on the integration supply chain (Gupta et al., 2019) and services (Parida & Wincent, 2019) that can be supportive to the circular business ecosystem. Synergizing can be achieved by of aligning individual and shared interests and developing common strategies and goals (Konietzko et al., 2020a). Communication & Sharing sprouts from the importance of data, knowledge and information sharing (Konietzko et al., 2020a; Tate et al., 2019; Parida et al., 2019). Innovation & Learning is a joint effort in an ecosystem, as it entails joint problem solving (Tate et al., 2019) and possibly co-creation (Lacy et al., 2020, p.287). Lastly, Adaptation & Restructuring originates from the commitment of customers (Konietzko et al., 2020a) and investors needed and the importance of trust (Konietzko et al., 2020a) and cohesion (Cramer, 2020) in an ecosystem.

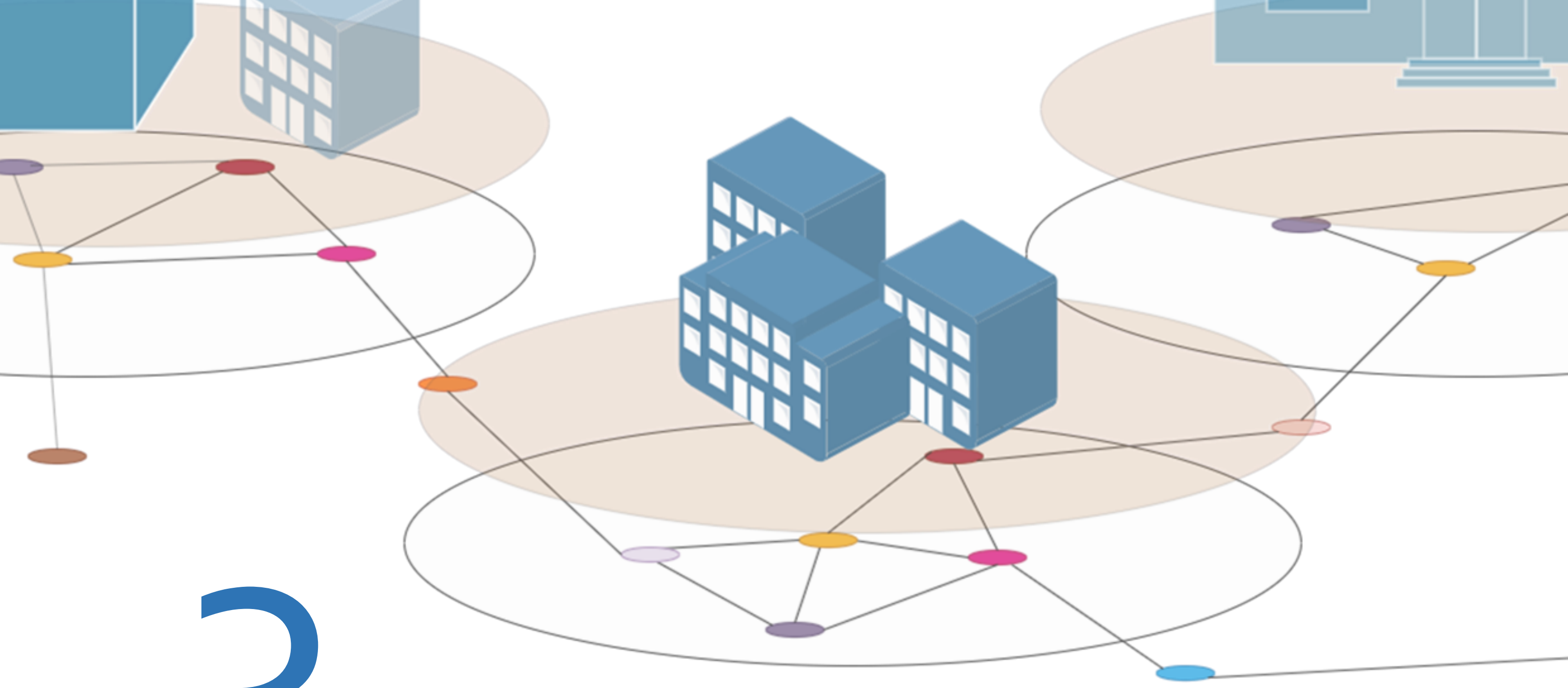
The **Change** dimension is the process of shifting from one business ecosystem configuration pattern to another circular configuration pattern. Renewal and co-evolution could be specified in more descriptive categories according the literature found on circular business ecosystems. Business ecosystems can be helpful to capitalize on new trends (Parida & Wincent, 2019). They can bring competitive and strategic advantages. Competitive advantages, like higher productivity and better resource use, market growth (Parida et al., 2019), branding (Lacy et al., 2020, p.291). But also, strategic advantages like less dangerous jobs, greater transparency between ecosystem actors, differentiation of product offerings and cost leadership (Parida et al., 2019). Besides, there are also mutual benefits like sharing costs and profits. Resultingly, the original category Co-evolution is replaced by the category New Advantages. Additionally, a circular business ecosystem collaboration can help to minimize risk to future regulations and becoming engaged in shaping of future regulations (Lacy et al., 2020, p.291). In a new or transformed ecosystem that works towards new goals, some new actor' roles need to be introduced a configuration patterns need to be redefined. This results in the new categories Pattern Shift and Roles Shift instead of Renewal.

An overview of all adaptations and extensions are displayed in Table 2.

Table 2. 6C-framework of Rong et al. (2015) tailored to a 6C-framework to analyze a circular business ecosystem

Dimension	Description of dimensions to analyze an IoT-business ecosystem, by Rong et al. (2015)	Description of dimensions to analyze a circular business ecosystem
Context	*environmental features of the supply network.* 1. Life Cycle Stages 2. Drivers 3. Barriers 4. Missions	environmental features of the circular supply network 1. Life Cycle Stages, i.e. emerging, established, leading and ultimate (Lacy et al., 2020) 2. Drivers Parida & Wincent, (2019); Gupta et al. (2019) 3. Barriers 4. Mission, i.e. impact reductions, (Lacy et al, 2020) or environmental targets (Parida et al., 2019)
Construct	*infrastructure and structure of business ecosystem.* 1. Structure 2. Infrastructure	*infrastructure and structure of a circular business ecosystem.* 1. Structure, e.g. actor balance (Tate et al., 2019) 2. Infrastructure
Configuration	*operational mechanisms in supply network and how these form configuration patterns.* 1. Pattern 2. External Relationship	*activities in circular supply network and how these form configuration patterns.* 1. (Circular) Business Process* 2. (Circular) Business Models*
Cooperation	*collaboration and governance mechanisms of the ecosystem.* 1. Coordination Mechanism 2. Governance System	*collaboration and governance mechanisms of the circular business ecosystem.* 1. Network Characteristics*, e.g. dense and heterogeneous network (Tate et al., 2019) 2. Governance Mechanism* e.g. negotiation, nurturing and standardization (Parida et al, 2019)
Capability	*key success features of the ecosystem.* 1. Integration & Synergy 2. Learning Adaptability 3. Communication & Accessibility 4. Adoption & Mobility	*key success features (or capabilities) used in the circular business ecosystem.* 1. Integration & Synergizing* 2. Innovation & Learning* 3. Communication & Sharing* 4. Adaptation & Restructuring*
Change	the process of shifting from one business ecosystem configuration pattern to another 1. Renewal 2. Co-evolution	the process of shifting from one business ecosystem configuration pattern to another circular configuration pattern 1. Roles Shift 2. Pattern Shift 3. New Advantages (e.g. strategic, competitive and mutual advantages)

**adapted by the author upon literature on circular (business) ecosystems*



3. Methodology

Methods used to analyze empirical data

3. **Methodology:** methods used to analyze empirical data

This Methodology section is about how empirical data is collected, analyzed, and validated in this research.

3.1. Research Approach

To answer this main question a qualitative research approach is used. A qualitative research approach is useful when there is a high degree newness of the topic studied, the topic has not yet been studied for a certain group and existing theories do not apply to this group (Morse, 1991). The first two criteria are met as there has not yet been an application of circular business ecosystem to the built environment. Rather only manufacturing industries are studied with respect to circularity and the business ecosystem perspective (e.g. Hsieh et al., 2017, Tate et al., 2019). The business ecosystem perspective builds on earlier supply chain network ideas to incorporate other stakeholders and organizations in business operations (Zucchella, 2019a, p.82). Because of the high degree of collaboration needed to close the loop in the building supply chain (Leising et al., 2019), a circular business ecosystem perspective seems useful to gather insights in collaboration and supply networks in the built environment. Regarding the third criteria, a circular business ecosystem perspective seems preferable over describing merely the circular business model, as this does not provide a holistic overview on how circular business operations are established. So far, no theoretical framework was found in circular business literature that provided such a holistic overview. Qualitative research also tolerates space for innovative ways to do research and to make use of frameworks designed by fellow researchers (Creswell, 2009). This corresponds with the approach to initially use the 6C-framework as a starting point for analysis, that was originally made to provide a comprehensive overview of IoT-business ecosystems. The 6C-framework by Rong et al. (2015) is a solid base for finding evidence but needs tailoring for the purpose of providing a comprehensive overview of circular business ecosystems.

3.2. Case study research and data collection and verification

In this study, a case study method is applied to answer the third sub research question. A case study method is valuable when the topic of interest is in an early emergent stage and there are no suitable prior theories available (Eisenhardt, 1989). Case study research need a diversity in data collection methods to collect in-depth information about the cases that reflect a certain activity in a certain number of time (Stake, 1995).

3.2.1. Data collection

Data was retrieved by semi-structured in-depth interviews. Semi-structured interviews are a mix of open-ended and close-ended questions which leaves room for discussion (Adams & Newcomer, 2015, p.493). In this inquiry, the latter may result in new unforeseen codes to further refine the adapted 6C-framework as proposed in the previous chapter. Furthermore, conducting semi-structured interviews has the advantage that respondents are not hampered by telling their thoughts and experiences as a result of the attendance of other participants (e.g. in case of a focus group setting) (Adams & Newcomer, 2015, p.494). In this study, the unit group of analysis are demolition contractors. The demolition environment is characterized by a competitive rather than cooperative environment that makes a one-person in-depth semi-structured interview most suitable for retrieving data. The drawback of conducting semi-structured interviews is that is a time-consuming method to gather data. As a result, 4 interviews (1 per case) were conducted within the time provided for this thesis. Such a small sample size makes it more difficult to generalize the final findings.

For the data collection of the case study research, a total of four demolition contractors were selected to study the circular business ecosystem(s) of demolition contractors. They are assumed to orchestrate certain circular business ecosystems for building materials, as they dismantle these from the old building stock. The selection of the demolition contractors was based upon the presence of three criteria: 1) the presence of circularity projects on their website or in news articles, 2) the presence of a marketplace and 3) public information availability on their projects. All selection criteria and subsequent fulfilment of the four cases are found in Table 3.

Data was collected during the 23rd of March and 30th of May 2020. The list of interviewees is found in Table 4. The information gathered by the interviews was audiotaped, while taking notes. In case the audiotape was failing these notes were used. The interviews followed an interview protocol that consisted of 25 questions that were subdivided in the 6C-dimensions. The questions in the interview protocol were based on the tailored 6C-framework that resulted from the previous chapter. The interview protocol can be found in Appendix C.

Table 3. Cases criteria for demolition contractor case-studies. Two companies have had their own marketplace, whereas the two other companies make were having an online shared marketplace to market salvaged materials.

Criteria	Case A	Case B	Case C	Case D
Experience with circular projects	Yes	Yes	Yes	Yes
Marketplace	Yes, shared	Yes, self-owned	Yes, self-owned	Yes, shared
Data available	Yes	Yes	Yes	Yes

Table 4. List of interviewees and interview time.

	Company	Function Interviewee	Interview Time (min/p)
Case A	Demolition contractor	Program Manager Digital Transformation & Circularity	116
Case B	Sustainable subsidiary of demolition contractor	Operational Director	86
Case C	Demolition contractor	Commercial Director	72
Case D	Demolition contractor	Branch Manager	84

3.2.2. Background to cases

To classify the cases on small, large, and medium size demolition contractors the definition from the sectoral rapport on Dutch demolition contractors is used. According to Kok & Koning (2019) a demolition contractor with less than 10 employees is considered a small contractor company, whereas a demolition contractor with more than 50 employees is considered a large company.

Demolition contractor A: Large demolition contractor and co-founder of an innovative circular online platform that offers a marketplace for salvaged materials and future-matchmaking

The other demolition contractor A has around 200 employees. The company moved from the traditional demolishing practices of the early 90s towards the current focus on recovering materials and application elsewhere. When receiving an application for a demolition project, they consider a circular application for useful salvaged materials in the old building stock. The company operates **two hubs (one for suspended ceiling and one for wood)** and is part of the committee of an online platform that provides an online marketplace for salvaged building materials. This online platform was initiated in 2018 together with a couple of other demolition contractors and an engineering company. They use an **online platform to market their salvaged materials before dismantling** takes place. Furthermore, they participate in a hub for suspended ceilings refurbishment with other demolition contractors that are connected to the platform. **They did several circular C&D projects**, covering the whole process from demolition to construction.

Demolition contractor B: Middle-size demolition contractor with sustainable subsidiary marketplace

The demolition contractor was founded in 1953 and concerns demolition and asbestos remediation practices. It is a **middle-size family company** with around 40 employees. They conduct all kind of demolition projects. The idea that building materials should rather be given a second life was grounded historically in the company's first business operations. The sustainable subsidiary of the company was founded in 2008. The subsidiary involves **a physical marketplace supported by a web shop** for several salvaged materials from their demolition practices. They sell all kinds of salvaged materials, like wooden beams, roof tiles, wooden plates, iron profiles, steel profiles, insulation materials, machines such as installations, aggregates, but also washbasins, sanitary, switchgear, electronics, fencing, kitchens to private individuals. Besides, they offer dismantling and pre-demolition audits. They have **participated in a couple of circular C&D projects** in which they where challenged to reuse salvaged building materials from old building stock into a new construction on-site.

Demolition contractor C: Market leader in demolition activities in the Netherlands with a marketplace and own C&D waste recycling facilities

The demolition contractor was founded in 1993 and currently has a total of around 400 employees. It is the **market-leading demolition contractor** of the Netherlands. The company's philosophy is centered around high value reuse of materials. They have six recycling facilities to sort and create clean fractions out of C&D waste. In addition, they offer recycling services for businesses and events and offer asbestos remediation practices. The demolition contractor is market leader on demolition practices in the Netherlands. In 2019, a subdivision of the company was created to explore high value reuse and recycling of salvaged building materials. Currently, this subdivision has its own **wooden beam refurbishment hub** and its own web shop in which salvaged materials from own demolition operations are sold. Their **own web shop** is connected to **their physical marketplace** where they sell all kind of building materials and components like doors, door fittings, insulation material, ceiling plates, carpet tiles, partitions, sanitary facilities, fire extinguishing systems, etc. They **worked in several circular C&D projects** that involved high circular ambitions on salvaged material reuse.

Demolition contractor D: ***Large demolition contractor that markets salvaged materials in advance***

This demolition contractor was founded in 1949 is one of the larger demolition contractors in the Netherlands. Innovation and sustainability were already part of their operations since the foundation. For example, in the early days they recycled concrete into own company equipment, like blocks for railings. The company has around 220 employees and is part of a larger company group. Besides demolition and asbestos remediation, they also offer environmental engineering solutions and road construction. The demolition division has around 70 employees. Better reuse or recycling of retrieved materials has always been part of the company's approach towards demolition. They standard retrieve common elements that are fast and easy to dismantle in every project and are keen to do projects with high circular ambitions. They also constantly try to find circular solutions for salvaged materials and are part of collaborative refurbishment hubs. They do not have any storage facilities for storing salvaged materials for third parties and therefore make use of the **online platform** that was mentioned by company A as well. Here, **they offer some salvaged materials in advance of demolition**. They also **participated in a couple of circular C&D projects**, of which one was an award-winning circular C&D project. They have a **suspended ceiling plate hub**, together with other partners (amongst which Demolition contractor A) where ceiling plates are delivered and upcycled. They also have several **other hubs,** and they have regular customers, where some salvaged materials standard goes to. They for example have **a network of regular customers** for steel beams, but also installations, frames, doors etc.

3.2.3. Data reliability, validation, and triangulation

To achieve data reliability, a structured research design and the interview protocol were used. This also makes the research replicable and transparent. Also, academic researchers were asked to comment on the coding scheme and the interview protocol. Comments from supervisors helped to strengthen and refine the research structure, reporting clarity, research design, argumentation, and findings.

To validate the primary interview data, secondary data was gathered from external sources, like companies' websites and new articles. Additional data was used if information from the interviews was unclear. As a drawback to this research the cases were only analyzed by one researcher that results in a certain researcher bias. Hence, there is a bias towards own interpretation of results. However, to make this bias as small as possible the line of argumentation is made as clear as possible and checked by academic supervisors.

Lastly, to verify findings and triangulate data one-to-one conversations were held with practitioners, to discuss the practical relevance and practical accuracy of the main findings. The results of these sessions are added in the discussion section and were used to draw final conclusions.

3.3. Coding process: hybrid coding approach and code scheme

Yin (2009) proposes to have a general analytical strategy when it comes to analyzing the data gathered. In this study, a combination of coding based on predetermined codes and emerging codes from the interview data is used for data analysis. This is referred to by Rong et al. (2015) as a "hybrid coding approach". This coding method is preferred over open coding, as open coding is more suitable for Grounded Theory instead of using a theoretical lens as done in this inquiry. Still, since the 6C-framework is still open for improvement and further tailoring to circular business ecosystem research it is useful to allow for some open coding. For example, the tailored code scheme from the literature review may not necessarily capture all codes or may include redundant codes. After all, the final code scheme should provide a comprehensive overview of the circular business ecosystem.

For new codes to emerge during the coding analysis, the rules of Saldaña (2013) on codes are used. Saldaña (2013) explains that a code in qualitative inquiry should always be a "*summative, salient, essence-capturing, and/or evocative attribute*" (Saldaña, 2013, p.3) and clustering should be based upon regularity (pattern) and similarity to form a category. In the coding process, all text was descriptively coded by attaching several lines of text (e.g. multiple sentences or paragraphs) in primary and secondary data to pre-set or emerged codes.

3.3.1. From the original code scheme of Rong et al. (2015) to a code scheme to analyze circular business ecosystems

The final code scheme displayed in Figure 3. All code definitions are found in Table 5 and more elaboratively explained in Appendix D2. The code scheme adaptations made during the coding process other than described in the following examples, are found in Appendix D1. This Appendix also include the original code scheme of Rong et al. (2015).

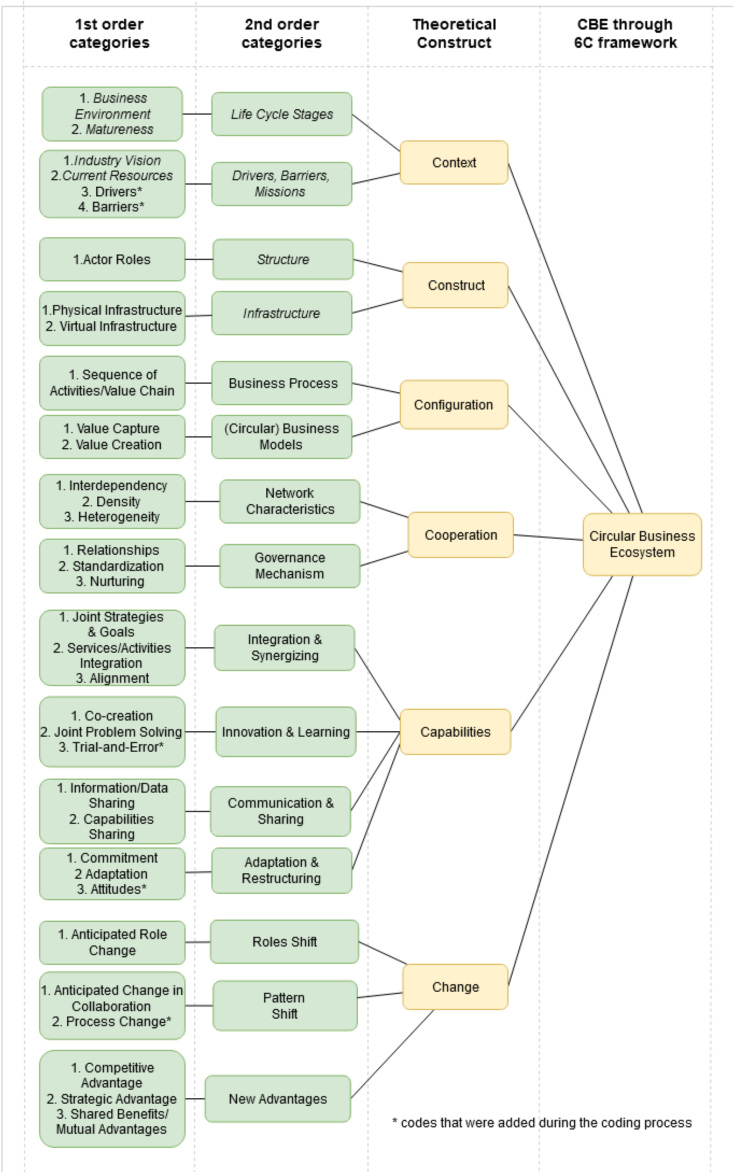


Figure 3. Final Code Scheme. The codes that were used for the coding analysis are the first order categories. The first order categories are described in the result section. These first order categories together explain the second order categories. The second order categories describe the 6C-dimensions. The italic categories are those that remained the same as the code scheme of Rong et al. (2015).

Some similarities and adaptations to the initial code of scheme Rong et al. (2020) and the introduction of new codes during the coding process, are illustrated below:

- ***Similarity**: keeping the original codes from the framework of Rong et al (2015)*
  Example: The 2nd order and 1st order categories of the Context dimension remained the same as in the original codes scheme. The codes remained the same as these codes were assumed to reflect the understanding of why circular supply network(s) emerge(s) sufficiently. However, the interpretations of these categories were detailed to a circular business ecosystem. For example, Industry Vision refers in this inquiry to ambitions or mutual goals in relation to circularity in the industry.
- ***Adaptation**: adapting the original codes from the framework of Rong et al (2015)*
  Example: The Cooperation dimension was rather best described by Network Characteristics, that consisted of the dimensions Interdependency, Density and Heterogeneity. To describe the structural complexity of relationships, Tate et al. (2019) uses a description of the density

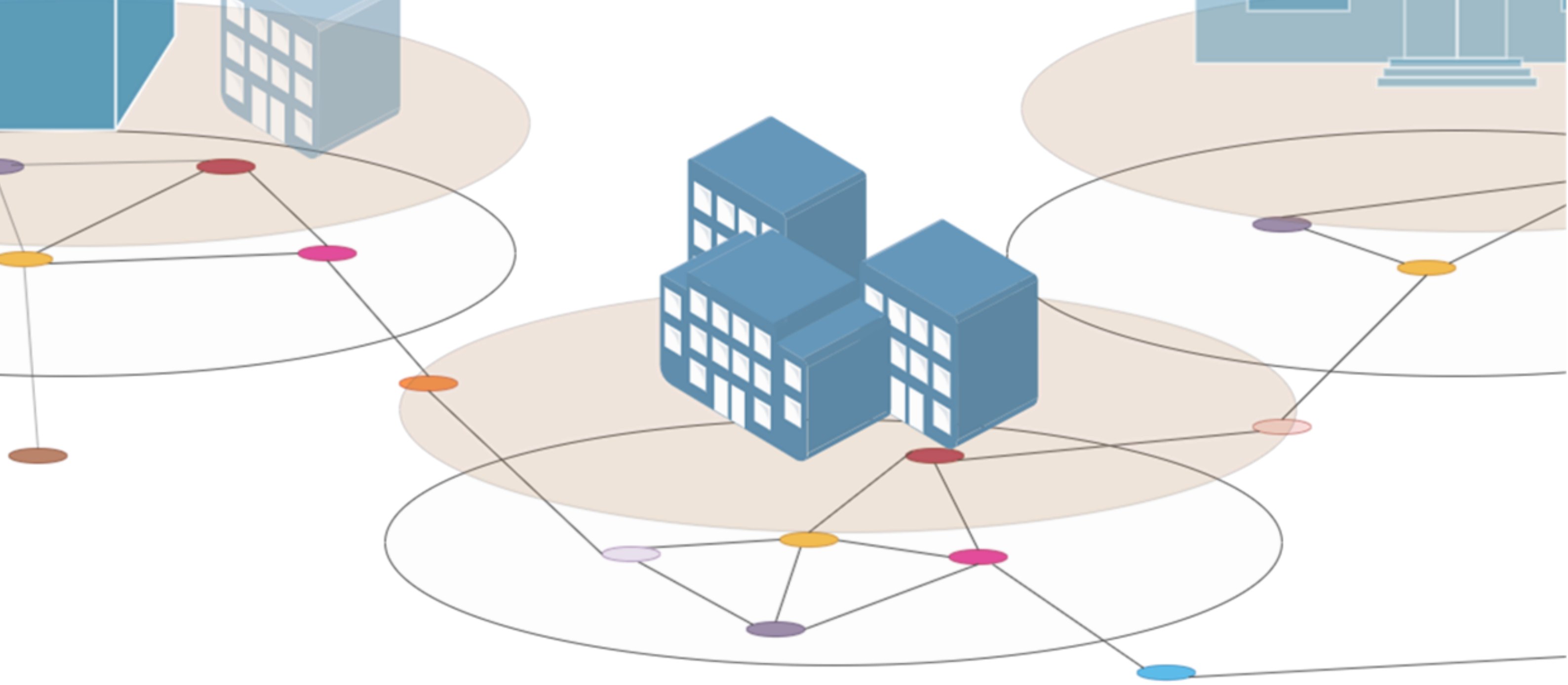
of the network, network complexity and interdependency. The network complexity dimensions were only reduced to the number of (different) actors, summated to the category: Heterogeneity. Heterogeneity was chosen as the networks in circular business ecosystem are characterized by a diverse group of actors (e.g. scavengers, recyclers, producers, consumers) (Tate et al., 2019). Parida et al. (2019) explained all kind of means to shape the circular business ecosystem: nurturing and standardization. This were assumed to be essence capturing codes of what is going govern the ecosystem. Relationships as a code was added as a summative code to describe certain relationships mentioned if they were formal, loosely, or informal, temporary, or long-term.

- ***Emerging codes****: adding new codes that were retrieved during the coding analysis*
  Example: The code Attitudes was added to complement the codes Adaptation and Commitment in the subcategory Adaptation and Restructuring, as it became clear from the interview data that different attitudes are required to fulfill ambitions of high value reuse and recycling. Besides, the interviewees often mentioned valuable insights in the Barriers and Drivers to operating more circular. Therefor, these extra codes were added next to Current Resources and Industry Vision to describe the subcategory Drivers, Barriers and Mission. In the coding process five codes were added: Attitudes, Barriers, Drivers, Process Change and Trial-and-Error. For all changes made in the code scheme during the coding process, see Appendix D1.

Table 5. Summary of explanations of all final codes

Dimensions	2ndorder category codes	1st order category codes
Context: *environmental characteristics of the circular supply network*	**Life Cycle Stages** *to the degree of circularity*	**Business Environment:** *environment of where the ecosystem operates in* **Matureness:** *degree of circularity of material flows in the ecosystem*
	Drivers, Barriers, Mission *of the ecosystem*	**Industry vision:** *the mutual goal/ambitions on circularity of the ecosystem* **Current Resources:** *resources that are used to create value and conduct the business operations* **Drivers:** *drivers to ecosystem actors to operate circular* **Barriers:** *barriers to ecosystem actors to operate circular*
Construct: *infrastructure and structure of a circular business ecosystem*	**Structure** *of the ecosystem*	**Actor Roles:** *all ecosystem actors and their roles*
	Infrastructure *of the ecosystem*	**Physical Infrastructure:** *physical infrastructure (e.g. logistics, storage) that supports the ecosystem* **Virtual Infrastructure:** *virtual infrastructure (e.g. block chain, data management) that supports the ecosystem*
Configuration: *activities in circular supply network and how these form configuration patterns*	**Business Process** *of the supply network in the ecosystem*	**Sequence of Activities/Value Chain:** *value chain or sequence of activities of circular operations in the ecosystem*
	Business Models *of the supply network in the ecosystem*	**Value Capture:** *how earnings are retrieved (and shared) from circular operations in the ecosystem* **Value Creation:** *how value is created from circular operations in the ecosystem*
Cooperation: *collaboration and governance mechanisms of the circular business ecosystem*	**Network Characteristics** *of the ecosystem*	**Interdependency:** *dependency of ecosystem actors on one another* **Density:** *spatial distance in circular practices and the number of actors* **Heterogeneity:**

		the number of different actors
	Governance Mechanism *of the ecosystem*	**Relationships:** *forms in which the actors in the circular business ecosystem collaborate* **Standardization:** *activities and investments carried out to formulate industry requirements* **Nurturing:** *(early) investments and guidance in the ecosystem by orchestrators*
Capabilities: *capabilities used in the circular supply network*	**Integration & Synergizing** *of circular operations in the ecosystem*	**Joint Strategies & Goals:** *joint strategies and goal development in the ecosystem* **Services/Activities Integration:** *integration of supply chain or activities in the ecosystem* **Alignment:** *alignment of goals and strategies of actors and the ecosystem*
	Communication & Sharing *between ecosystem participants to carry out circular operations in the ecosystem*	**Information/Data Sharing:** *data transparency on material value and business information* **Capabilities Sharing:** *knowledge or expertise sharing in the ecosystem, or sharing business capabilities like supply chain management*
	Innovation & Learning *that takes place in to carry out circular operations in the ecosystem*	**Co-creation:** *value created by interaction between ecosystem actors* **Joint Problem Solving:** *jointly tackling of problems in the ecosystem* **Trial-and-error:** *process of trial-and-error to achieve fruitful circular operations in the ecosystem*
	Adaptation & Restructuring *that is required to carry out circular operations in the ecosystem*	**Commitment:** *commitment of ecosystem actors to engage in circular operations* **Adaptation:** *adaptations of ecosystem actors to the circular operations in the ecosystem* **Attitudes:** *attitude changes required to fulfill circular operations in the ecosystem*
Change: *the process of shifting from one supply network to a circular supply network*	**Roles Shift** *that is required to shift from linear to a circular supply network in the ecosystem*	**Anticipated Role Change:** *role change required of ecosystem actors to fulfill circular operations in the ecosystem*
	Pattern Shift *that is required to shift from linear to a circular supply network in the ecosystem*	**Anticipated Change in Collaboration:** *collaboration change between ecosystem actors to fulfill circular operations in the ecosystem* **Process Change:** *changes required to the business processes in the ecosystem to make it more circular*
	New Advantages *that provide the shift to circular operations in the ecosystem*	**Competitive Advantage:** *competitive advantages that make operating in the ecosystem preferable* **Strategic Advantage:** *expected future advantages that makes operating in an ecosystem preferable* **Shared Advantages/Mutual Benefits:** *benefits that are realized more than one participant in the ecosystem*



4.

Results

The case study analysis of four demolition contractors

4. **Results**: case study analysis of four demolition contractors

This chapter concerns results. The information on all cases is used to describe the codes in the 6C-framework. Important to note is that Configuration dimension is described before Construct, as this provides more guidance to the reader. The key insights of this chapter are summarized in the end of the chapter.

4.1. Background

Interviewee A is program manager Digital Transformation and Circularity at a large demolition contractor and co-founder of an innovative circular online platform that offers a marketplace for salvaged materials and future-matchmaking. The interviewee has worked on several circular C&D projects. At every demolition project they consider high value application of salvaged materials. For suspended ceilings, the contractor operates a hub together with 11 other demolition contractors as part of innovative circular platform operated by a consultancy company. This is an innovative platform that tries to accelerate the circular economy in the built environment. The platform offers an online marketplace where demolition contractor partners can upload their future freed salvaged materials and their specifics. Interviewee A makes use of this online marketplace as well to market for example tapestry, doors, windowpanes, installations, air conditioning systems, boilers etc. Besides, the contractor is part of a consortium that offers 95-97% recycled concrete. Also, part of their wooden beam waste stream is refurbished by social return on investment (SROI) parties. In addition, part of meranti wood is remanufactured in a carpentry factory to new windowpanes.

Interviewee B is operational director at a middle-size demolition contractor with a self-owned sustainable marketplace as subsidiary. A small portion of the salvaged wood from their demolition projects finds it way to a carpentry factory. The wood is processed into wooden windowpanes and inner walls. Furthermore, they resell roof tiles to a local party. But these are all pilot scales. They have their own physical market (and storage) place where they resell easy-to-dismantle components and materials from their demolition projects. They also collaborate with a party that processes concrete into gravel replacement and are currently exploring the options to high value recycle concrete. For four years they operate an Innovation Hub that connects students to their company. Topics of interest are data management and environmental impact calculations of salvaged and secondary building materials. Currently, interviewee B is participating in a testing-ground set up for the first time. Here, they collaborate in a consortium to realize a circular C&D project with partly salvaged materials. They have had such a challenge to establish high value reuse of materials in collaboration with other C&D actors and the client, before.

Interviewee C is commercial director at the Dutch market leader in demolition operations that has a self-owned marketplace and six C&D waste recycling facilities. Here they sort and process the materials for secondary material customers. Besides, they also process industrial waste. They also have a physical marketplace with a web shop where they offer salvaged building materials and components retrieved from their demolition projects. This includes offerings like doors, installations, wood, building hardware, stairs, lightning etc. Additionally, they have their own refurbishment hub where people with a distance to the labor market refurbish wood (e.g. slats, boards, beams etc.). Lastly, they also conduct circular C&D projects or deliver elements for direct application of to a local construction project. They are currently working on a white-label Circular Construction hub that becomes a refurbishment and logistic center where building contractor can immediately get refurbished secondary building material supply. This will a white-label hub, meaning it will be open to other building and demolition contractors to use as well. The collaborate with other parties to explore the opportunities of digitalizing salvaged materials of future demolition projects.

Interviewee D is branch manager of a large demolition contractor. As a demolition contractor, they have carried out several circular demolition projects and were part of a construction team collaboration on a C&D project. They are also building their new office location from as much reused materials and components as possible, from their own demolition projects. They are also partner of the innovative circular platform, likewise demolition contractor A. They make use of the same online marketplace and jointly operate the same suspended ceiling hub. They serve all clients from conservative to ambitious on circularity, but the latter has the preference. They continuously try to seek connections in the market and develop themselves to come up with new ways to achieve high value recycling and reuse of materials. They resell part of the salvaged materials to other hubs and parts (e.g. steel beams, installations, windowpanes, doors etc.) to regular buyers (i.e. salvaged material traders). These routes concern rather easy-to-dismantle components and materials. They have experience with high value recycling of concrete and are soon going to produce up to almost 100% recycled concrete. They for example recycle this concrete in poured concrete that they use for their infrastructure projects. In addition, part of the wooden beams is sold to regular buyers, but the other part is used to support infrastructure operations. This includes for example the creation of screen partitions for the construction of sewers.

4.2. Context

*4.2.1. **The Business Environment**: environment of where the ecosystem operates in*

Following the interviewees, the built environment can be characterized as a quite conventional and conservative market with mostly only client-contractor relationships. Interviewee A mentions that the competition between demolition contractors is severe. Currently, the realization of a project is characterized by putting everything in regulations and guarantees. The project process is mainly linear; a pattern of subsequently following parties that conduct their tasks and do not meet each other in the project process. For example, the architect and demolition contractor hardly never meet in a project process. Besides, investors and clients are generally mostly interested in the lowest price in the fastest time and well-acknowledged standards and certificates. However, there is slowly more cooperation between demolition contractors to together share ideas on circularity, orchestrate supply chains and share physical marketplaces.

Circularity is not new, historically it is the business model for demolition contractors to enhance demolition waste handling and reselling of high value salvaged building materials. Interviewee C mentions that striving for high value reuse and recycling of materials historically has provided financial advantages to demolition contractors. In turn, it can help to offer the best proposal to a tender. However, what is new is a **growing number of clients with circularity ambitions** in recent years. Especially from governmental bodies, as they act upon their leading role to fulfill the national ambition to have a fully circular economy by 2050. Also, the mindset towards circularity has changed in the past decade. As interviewee D explains, nowadays it is rewarded to construct a building that consists of circular materials, whereas applying new materials was highly rewarded 10-15 years ago. However, the market seems still dominated by tenders that are granted on lowest cost and time. As A formulates it in numbers: "*around 90% of the projects we do is currently not circular*". Interviewee D has the experience that high value use of materials accounts sometimes for 15% or 60-70% or even 100% of the tender requirements.

The companies operate in a **built environment characterized by a diverse range of type of buildings (e.g. utilities, flats, dwellings) built in different years that offer different materials**. For example, buildings built in the 70/80s have a different application of building materials than in other years. Also, in the last few decades more hazardous building materials were applied, like asbestos and glass wool. Hence, it is difficult to determine what materials are applied without any proper pre-dismantling assessment. Also, as interviewee B explains, the state in which materials are retrieved from the building is incredibly dependent on the dismantling practice applied.

Besides, secondary and salvaged building materials compete with their primary substitutes in price, quality, **safety requirements and guarantees**. For some secondary materials that are increasing in price (e.g. concrete granulate as granulate replacement in new concrete) business models are sufficient, whereas for other materials it is still difficult to break-even. For direct application of salvaged materials in construction projects this is similar: sometimes these projects break-even.

*4.2.2. **Matureness:** degree of circularity of material flows in the ecosystem*

All demolition contractors have started to orchestrate collaborations to achieve high value reuse and recycling over the past years. These different kind of collaborations resulted in different routes to recycling and reuse for several specific components or materials.

- Two of them have recently established together with other demolition parties a route for **suspended ceilings refurbishment** and two of them are currently operating routes for **wooden beams refurbishment**.
- Two of them are expecting to **recycle old concrete to almost 100% new concrete** nearby soon. One of the companies is currently working towards increasing the number of gravel substitute applied in recycled concrete. It likes to **enhance the number of gravel substitute delivered from old concrete**.
- One company recycles gypsum plates in Belgium to 100% new gypsum plates.
- They all have an assortment of products they sell on marketplaces that is quite broad. For example, **doors, door fittings, insulation material, ceiling plates, carpet tiles, partitions, sanitary facilities, fire extinguishing systems**, **wooden beams, roof tiles, wooden plates, iron profiles, steel profiles, insulation materials, machines such as installations, aggregates, but also washbasins, sanitary, switchgear, electronics, fencing, kitchens**
- All participants are currently busy with **exploring routes for other materials or components as well (e.g. sanitary, other wood types, carpet tiles, masonry).**

In mass percentages interviewee B estimates that around 1% is circular applied from the old building stock, interviewee C estimated for his company around 20% and interviewee A for his company around 8%. This is expected to increase significantly if concrete can be high value recycled as this is often the largest percentage of the total mass of buildings. However, the exact percentage differs per project. As A illustrates; they have also carried out a project in which they reused almost all materials into a new modular construction.

*4.2.3. **Industry vision:** the mutual goal/ambitions on circularity of the ecosystem*

All interviewees believe that they move towards a future in which circularity is going to play a more important role. Except for concrete, circular salvaged material handling is predominantly perceived as a business model for the future. They all expect a growing number of tenders with circularity criteria. Besides, they expect certain regulations (e.g. carbon tax) that will enhance the circular business models applied to salvaged materials in the near future. Regarding current practice, interviewee C argues that we are now beyond the pilot scale phase and can move towards conducting more ambitious projects. However, he stresses: "*you definitely need pilot-projects to show that it is possible. When other people see it is possible, I do believe that the market for it continues increasing*". As interviewee B expresses demolition contractors are material suppliers of the future. Especially, since raw material supply is not infinite. Hence, they all will continue striving towards maximizing the number of useful high value C&D waste handling practices. They all acknowledge that this benefits the environment (e.g. pollution reductions) and society (e.g. employment of people with a distance to the labor market), but also has certain (future) financial benefits.

4.2.4. ***Current Resources:*** *resources that are used to create value and conduct the business operations*

The demolition contractors retrieve the salvaged materials for high value reuse and recycling from their demolition projects. Some of them have a marketplace to resell materials, others a network of buyers and some operate refurbishment hubs (jointly). They have the skills to conduct pre-demolition audits to inventory the present materials in the building stock and determine their potential for (direct) reuse, resell, refurbishment or recycling. The number of proper pre-demolition material inventories carried out depends strongly on the time provided by the client. All companies have **standard dismantling approaches**. If there is no extra time provided, there is only time for standardized dismantling approaches. This dismantling mainly focusses on easy-to-dismantle components that can be resold, for example on a marketplace, or refurbished or recycled, if the salvaged materials are suitable. Interviewee C explains that they have a dismantling teams standard at every project. **More than standard dismantling is executed upon the client's wishes to do so**.

When demolition contractors are involved in a circular C&D project (i.e. a project in which salvaged materials are applied directly to a new construction), they often retrieve the salvaged materials from several own demolition projects. The direct application requires human capital like cross-disciplinary technical and regulatory knowledge.

4.2.5. ***Drivers****: drivers to ecosystem actors to operate circular*

All mention an "intrinsic logic" that drives the companies towards operating circular. This logic can be summarized as the **intrinsic logic that one should not waste valuable materials, since materials recovery can benefit the environment, society and prevent future scarcity issues**. Besides, **anticipation to regulations and trends** steered them towards innovative practices. In regards, the interviewees mention certain regulations and trends that are expected to lead towards an increased demand (and price) for circular building materials and components. These are: increased use of quality criteria on circularity in tenders; living up to the Concrete Agreement; future carbon taxes and future obligatory reporting on MPG performance. Besides, participating in circular pilot projects are ways to demonstrate and explore abilities to achieve high value reuse and recycling. Besides, interviewee C mentions **financial benefits** as an additional motivation.

4.2.6. ***Barriers:*** *barriers to ecosystem actors to operate circular*

Generally, **buildings in the current building stock are not designed to dismantle for proper waste handling in the end-of-use phase**. As interviewee B explains, part of the materials applied cannot be recycled or reused in a purposeful way because of their properties, like glass wool and asbestos. Other materials you simply cannot reuse or recycle because they are purred, kitted, or glued together. The material connections can decrease the number of building materials that can potentially be reused. As interviewee D explains: "*if you have steel beams that are welded together, for example, then you have already a more difficult story than when we could bolt the steel beams apart, so to speak*".

The time for dismantling provided by the client can be a constraining factor in different ways. *In the pre-demolition phase*, interviewee C mentions that the **limited time provided to inventory materials before dismantling practices** is hampering a thorough inventory of building materials. If time is constrained, this can imply that there is no time to inventory the materials applied behind surfaces like ceilings and (partitioning) walls. *In the circular demolition or dismantling phase*, **it takes more time to dismantle building materials** in comparison to demolishing practices by cranes. The

practice of dismantling is also more costly in comparison to demolishing by crane, because it involves more labor. *In the after-dismantling phase*, refurbishment routes can also become costly in comparison to their new primary substitute as more labor is involved in the process. Additionally, interviewee C mentions also mentions **the sales market for secondary materials is not opaque.**

Besides, there is an **absence of (grounded) standards that signal the grade of circularity or environmental impact reduction** can convince investors or clients of added value. Currently, there are certain standards on the market that signal achievements with respect to sustainability (and circularity). On product level e.g. Forest Stewardship Council (FSC) certificate for wood and Concrete Sustainability Council (CSC) certificate for concrete. On building level, there are standards like BREEAM and LEED that signal sustainability performance. Some clients ask for specific known **standards and guarantees, that are not provided or difficult to provide for the secondary building materials**. For example, in the case of concrete, some clients simply want a CSC-certificate (i.e. certificate of the Concrete Sustainability Council) because that is BREEAM acknowledged, meanwhile this certificate can currently not be provided for the 100% recycled concrete.

Interviewee C also points out that **setting too specific tender requirements** can limit the people's creativity that the outcome may be reached in the end (or not), but nothing more.

Besides, **matching supply and demand of salvaged building materials** can be a difficult challenge. As interviewee D mentions: "*… you would prefer to reuse them as high-quality as possible, but at some point, it is like: can you get rid of them? I can have toilet pots in stock, so to speak, tomorrow or next week, but if no one wants them, then it is of no use to me*." For example, in the case of steel beams, if there is no immediate demand, the beams will end-up being recycled instead of reused. Besides, as interviewee B explains, if a building contractor demands a certain material supply at a certain time with certain requirements fulfilled (e.g. certain measurements, without user traces) it is difficult to guarantee supply. Hence, purchasing new materials is much easier for the building contractor. Additionally, for direct reuse it can also be the case that salvaged materials and components are lacking soundproofing, fire resistance, color, or height demands. Lastly, another factor that can restrict the customer base for high value reuse from a carbon emission perspective is the transport distance. The **longer the transport distance, the higher the environmental impact**.

4.3. Configuration

The Configuration dimension entails all activities in circular supply network. This involves a compilation of the several different configuration patterns (from now on called: routes) to high value reuse and recycling. In total there were found 11 routes. An overview of all routes to high value reuse and recycling are displayed in Table 6a displays the value chains and Table 6b displays the project collaborations. The following subsections explain these more in-depth.

Table 6a. Identified routes as *value chains* for salvaged materials

Description in section:	Value chains	Circular strategy	Mentioned by
4.3.1.1.	Secondary products via an online marketplace platform with product storage	Reuse	C, B
4.3.1.2.	Secondary products via an online marketplace platform without product storage with matchmaking before materials are freed from the building	Reuse	D, A
4.3.1.3	High value reuse via refurbishing via orchestrated circular supply chains (e.g. suspended ceiling, wooden beams) - *white-label hub*	Refurbish	D, A, C

4.3.1.4.	High value recycling via orchestrated circular supply chains (e.g. glass, concrete, masonry)	Recycling	D, A, B, C
4.3.1.4.	Product-as-a-service: fulfilling take-back schemes of materials or components that are owned by the producer	Reuse/ Refurbish/ Remanufacture	C
4.3.1.6.	Salvaged material used for own business operations	Reuse	C, D
4.3.1.7.	Salvaged materials sold to traders in salvaged materials	Resell	D

Table 6b. Identified routes for *project* application of salvaged materials

Routes	Projects	Circular strategy	Mentioned by
4.3.1.7.	Building-as-a-service: dismantling the building and rebuilding it elsewhere stays within the demolition contractor's domain	Reuse	A
4.3.1.8.	Off-site reuse and recycling of materials, matchmaking of salvaged building materials with local clients	Reuse/ Recycling	C, A, D
4.3.1.9.	Off-site reuse and recycling of materials, matchmaking of salvaged building materials with non-local clients	Reuse/ Recycling	D
4.3.1.10.	Direct on-site reuse and recycling of materials	Reuse/ Recycling	D, A

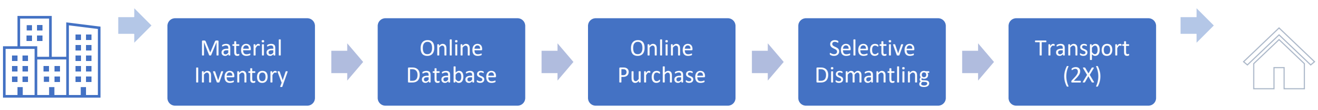
*4.3.1. **Sequence of activities or value chain**: value chain or sequence of activities of circular operations in the ecosystem*

4.3.1.1. Secondary products via an online marketplace platform with product storage

Two demolition contractors have their own online marketplace with storage. The companies solely own and operate these marketplaces and cover the logistics. Demolition contractor C has a customer base of small contractors (B2B) and no private individuals, meanwhile demolition contractor B sells only to individuals (B2C). The offerings on the website are clearly diverse ranging, from kitchen tables to carpet tiles to electronics to sanitary.

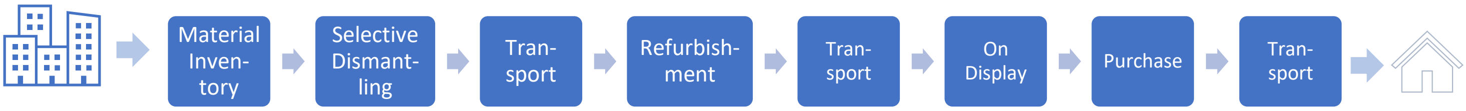
4.3.1.2. Secondary products via an online marketplace platform without storage with matchmaking before materials are salvaged

A consultancy company initiated an innovative circular platform that tries to accelerate circularity in the built environment. Both demolition contractor A and D are partners. The platform offers pre-demolition audits, offers material brokerage, and provides an online marketplace where demolition contractors can offer their salvaged materials before dismantling. Some of the demolition contractors also rent intermediate storage in case they cannot supply the salvaged materials at the moment of dismantling. Interviewee A explains how this works: "*We walk through the existing building with a tablet and app. We will then, for example, make an inventory of how many toilets there are, etc. and what you can do with. This then ends up in the online database on the platform. We also state the location and the time when it is released*". The buyers are a combination of all kinds of parties, from small and medium-sized contractors, architects to private individuals (although the focus is on the B2B market). But also, gardeners for trees and shrubs.



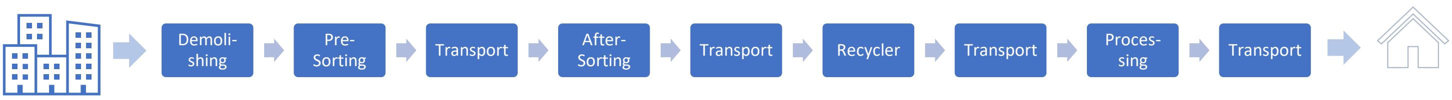
4.3.1.3. High value reuse via refurbishing via orchestrated circular supply chains (e.g. suspended ceiling, wooden beams) - white-label hub

Following from the interviewees A and C, refurbishment routes can help to match demand with supply as it allows for refurbishment steps that can create specific colors, fulfill measurement requirements, and allows for providing guarantees. Interviewees A and D initiated with around 10 other demolition contractors a chain for suspended ceilings. Interviewees A and C have created their own value chain for wooden beams. Demolition contractor D is currently exploring the opportunities of sanitary product refurbishment. Another company is collaborating with a building contractor to create a white-label hub in which product storage and refurbishment can take place. Here, secondary products can directly be supplied to building contractors. In the future, other demolition contractors can make use of this hub as well, as interviewee C describes: "*in the long run you cannot avoid that you use that kind of material hubs universally and together, because only then I think you do reach the level that it is profitable as well*". Sharing logistics characterizes this business process. For example, in the case of meranti wood refurbishment, interviewee A explains "*as soon as it is running and we experience how it goes, we say, we will scale it up to national via the online platform. So we are going to report all the demolition contractors in the Netherlands that we collect it in this and this way, then we are going to bring it together in that and that way, to those and those streets, and those different places in the Netherlands where we refurbish (...)*".



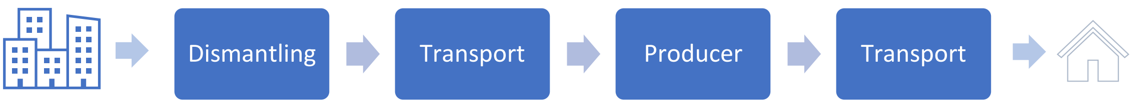
4.3.1.4. High value recycling via orchestrated circular supply chains (e.g. glass, concrete, masonry)

Different companies have different initiatives. Interviewee C is exploring the opportunities to have a higher content of gravel replacement in concrete, involving parties of the concrete industry. Interviewees A and D created a new approach towards concrete recycling by crushing and creating new concrete from old concrete in which the recycled content is almost 100%. Interviewee B explains that they - as other regional demolition contractors - brings their masonry and concrete waste to a local recycling company that creates clean fractions from the demolition waste. Demolition contractor C has its own recycling facilities where clean fraction of demolition waste is created.



4.3.1.5. Product-as-a-service: fulfilling take-back schemes of materials or components that are owned by the producer

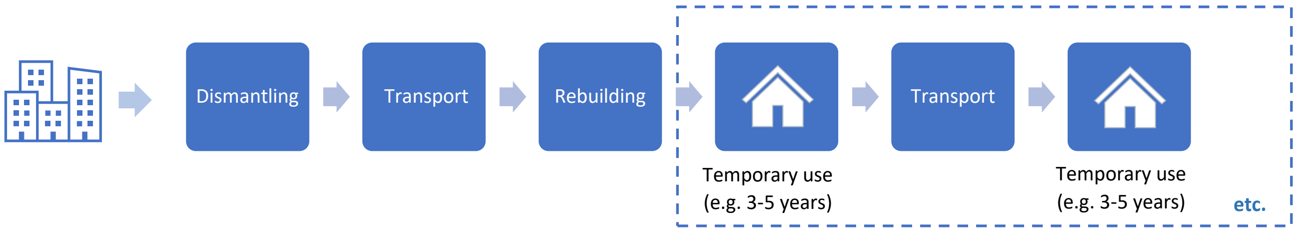
Nowadays, it occurs that the dismantling of buildings also involves dismantling of certain products that are still owned by the initial producer (e.g. carpet tiles, elevators, light fittings). As interviewee C formulates it: "*So before, when we got the key to a building, everything was ours. And what we are increasingly come across and going to come across is that: what a minute, those carpet tiles are still owned by the supplier and that lighting is still owned by the manufacturer and that elevator is still owned by its producer*".



4.3.1.6. Salvaged material used for own business operations: internal recycling
Interviewee C mentions that they reuse wooden beams for asbestos remediation practice. Interviewee D also mentions that they also use wooden beams in their infrastructure projects. He explains: "*There we also need wooden beams for the collection of cables and pipes, for making paneling or making those screens when constructing a sewer. And you need bulkheads for installation that we also make from released during demolition practices. You sometimes need steel beams for that purpose and we also partly reuse them ourselves, but partly they also go to the market*". Besides, they create poured concrete for infrastructure from old concrete.

4.3.1.6 Resell of salvaged materials to other salvaged material traders
Interviewee D mentions that they resell part of their salvaged components to regular buyers. In fact, they have a network of several traders. For example, they resell part of the salvaged materials to other hubs and parts (e.g. steel beams, installations, windowpanes, doors etc.) to regular buyers (i.e. salvaged material traders).

4.3.1.7. Building-as-a-service: dismantling the building and rebuilding it elsewhere stays within the demolition contractor's domain
Demolition contractor A is owner of a temporary building that is constructed of 98% reused material and serves as a temporary place to meet-up in the developing neighborhood. This project was aimed at establishing a temporary building with as much as reused and recycled materials as possible. The company illustrated by this case how it perceives the role of the company as becoming a 'maintainer of material stock'. The building placed only for a limited time (3-5 years) on the site and is then be rebuild elsewhere. As interviewee A formulates it: "*So we apprehend how to take it apart and we also understand how to put it back together and how to formulate it together so that you can easily take it apart again. And that is the ultimate example, that a building consists entirely of materials from dozens of other projects, all documented, including a material passport".* The demolition contractor captures value by renting the complex while keeping ownership. It created value by reusing 98% of the building materials applied.



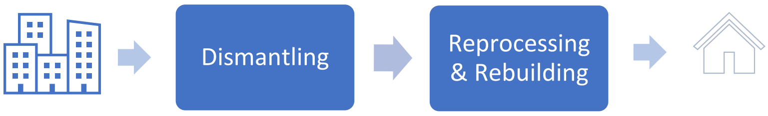
4.3.1.8. Off-site reuse and recycling of materials, matchmaking of salvaged building materials with local clients
Three of the four companies especially mentioned examples of this practice. For example, interviewee C mentions a case where they reused a steel construction on small distance to the demolition site and that project did break-even. In addition, interviewee A mentioned a case where they created a sheepfold from concrete from concrete from local demolition projects. They also fully dismantled a cold store and rebuild cold store elsewhere regionally with the same use and functionality.

4.3.1.9. Off-site reuse and recycling of materials, matchmaking of salvaged building materials with non-local clients

Demolition contractor D is using a structure from the West of the Netherlands to apply in a new construction in the East of the Netherlands. They use a steel construction and hollow slab floors from that building to build their own storage hall and new office.

4.3.1.10. Direct on-site reuse and on-site reuse and recycling of materials

Interviewees A, B and D specifically mention examples of projects where they achieved on-site reuse and recycling. Interviewee B mentioned that testing ground where they want to use the old building stock on site to create new buildings the construction team consisted of a building contractor, a demolition contractor, a client (a housing corporation), a processor of stony material, an advisory company, an architect, an party that is responsible for inventory of materials, a spokesman of tenants and a communicating party. Interviewee D illustrates a project: "*You have to imagine that we made ceilings from doors, we sawed blocks from masonry and turned it into an outer tile. We also built an outer facade of concrete chunks. We lifted a complete concrete carcass and placed it on a foundation and that foundation was again made of 100% recycled concrete.*" In another project they decided to leave a concrete carcass and strip the building.



4.3.2. ***Value Capture:*** *how earnings are retrieved (and shared) from circular operations in the ecosystem*

Three of the four companies are currently enhancing the number of processed bulk material they can cleanly deliver to the concrete industry. If bulk materials are supplied in satisfactory quality to the concrete industry you will get a positive return. For reusing components, the business model is not yet refined as the material characteristics needs to be known and it is difficult to meet the requirements in existing specification drawings (without any adaptation). Besides, proper dismantling of components is also costly as it is manual labor. However, **if there is a matchmaking of the salvaged materials to a construction project it is possible to create a business model**. As interviewee A describes the current situation "*currently you put real money on dismantling materials from buildings. So, if you only commit yourself to that practice you will go bankrupt. However, if you find an immediate connection with another project to which you can supply the dismantled materials then there is often a business model to be found".*

Interviewee D explains that implementing reused materials and components can also **reduce time and cost of projects** if they are immediately applied in another project. Regarding costs, the economic gains are that the materials itself are costless and **no (or less) disposal costs** are paid. Demolition contractor A had one case in which a were concrete floors could be reused in a close-by project, which resulted in only a few days of crane and a few kilometers of transport. This was a fraction of the normal time required to process concrete. Finally, a circular project does not necessarily have to be profitable but should cover all costs made.

Demolition contractors that constituted refurbishment routes together with a wholesaler and SROI parties, capture a **portion of the value from selling the secondary product for a certain market**

price at the wholesaler. The wholesaler receives a portion as well. The costs of processing the salvaged materials originate from the labor costs for dismantling and refurbishment activities and the costs of transport. For example, as interviewee A explains the time to retrieve suspended ceilings properly from a building requires 1.5 more time than regular demolition practice**. Upscaling refurbishment activities will create better business models.** Other demolition contractors joining the refurbishment route as well, creates more inflow of materials. For them, the costs of refurbishment are lower than regular disposal costs. Interviewee A explains that **cost risks are currently often covered by using subsidies or to fund one-time research trajectories**. Currently, the wooden beam refurbishment of demolition contractor C does not break-even but is expected to break-even in the future when demand increases (e.g. due to a carbon price or circular tender requirements).

The marketplace of company B is already running for a couple of years, but still generally costs more money than it pays-back. It stays difficult as labor costs are high and new building materials remain inexpensive. They are settling the difference, however in the future the company expects to capitalize on the circularity trend. The marketplace of company C almost runs break-even. No guarantees are provided by the demolition contractors. This is hampering the business model such that the customer base is generally limited to individuals and small contractors, architects or entrepreneurs that are intrinsically motivated to apply salvaged materials. Specifications like fire resistance and sound resistance of reused materials are difficult to identify. But also, products have often a unique character (e.g. color, use traces) or do not meet current building requirements (e.g. door measurements) that impedes matching demand with supply. **Value is captured by selling these diverse range of salvaged materials and components**.

4.3.3. ***Value Creation:*** *how value is created from circular operations in the ecosystem*

Interviewee D describes the challenge of circularity in the built environment as "*how can I build something new as inexpensively and as pleasant as possible and without also burdening the environment*." Within this ambition, social value can be created as well, as the companies of C and A show. They both employed people with a distance to the labor market for these **refurbishment practices generating SROI**.

Another value created is environmental value. **Substituting primary for secondary materials replaces the activity of extracting and refining primary materials**. The number of impact reduction depends on the specifics of the material (circular) supply chain and transport needed. For example, from the perspective of carbon emission reduction using salvaged lumber for windowpanes can have a larger carbon impact than using primary wood materials. This is due to the carbon capture of trees over their lifetime that cannot be counted for when reused. From a lifecycle perspective, diesel transports and refurbishment practices only enhance carbon emissions.

Interviewee C also mentioned the **esthetic value** that can be created by reusing salvaged materials. However, this is a quite subjective value as some people can also consider, for example reusing structures, as ugly or they simply do not mind.

4.4. Construct

4.4.1. ***Actor Roles****: all ecosystem actors and their roles*

Several actors were described by the interviewees. All parties described either have a role in fulfilling circular operations or an accelerative, mediator or supportive role.

4.4.1.1. *Academia* - *research support*

Demolition contractor B has an innovation hub were students explore ways to improve circular business operations. Like exploring the possibilities of material data registration and their added value. Interviewee D also briefly noted that they collaborate with universities.

4.4.1.2. *Architects* - *design from salvaged materials*

To work with salvaged materials, architects need to create buildings from available salvaged materials, which they are not accustomed to. Beforehand, they need to apprehend which and how the materials are retrieved from the building stock. They can also make use of products available from marketplaces.

4.4.1.3. *Building contractors* - *calculating and logistic partner role*

Building contractors understand how to apply salvaged building materials in constructions. Building contractors can also be involved in refurbishment hubs, where salved building materials are refurbished. This enhances logistic efficiency.

4.4.1.4. *Clients* - *demand projects with circular ambitions*

Projects are carried out upon the client wishes that need to involve somehow circularity. Clients also need to provide sufficient time to fulfill the ambitions. According to interviewee C small clients can be enthusiastic to reuse building materials. In addition, clients can also use salvaged building materials from their own to-be demolished building stock for their own new construction projects. As interviewee D formulates it '*… that is of course also a way of thinking that we like with our clients; that you take a glance within of what you could reuse within your own organization'.*

4.4.1.5. *Demolition contractor* - *value chain orchestrating role, dismantling, inventory, data, seller, internal reuse, and recycling*

All interviewees mention the advisory role as a demolition contractor to advise about the dismantling and reassembly of buildings in the beginning of the project process as very important to achieving circularity in the built environment. As interviewee D formulates it: '*We can indicate which materials are best to disassemble, how can we disassemble them, how they occur, what you can do with them and then the architect can start incorporating them into his design*'. Interviewee A describes the role of a demolition contractor in the circular economy as a depot manager: "*Basically you can summarize it as that we have become a material depot manager and that implies that we contribute ideas about how to dismantle and assemble buildings again".* Besides demolition contractors explore and develop ways to inventory, store, track and match secondary materials form the old building stock. Besides, demolition contractors have a proactive role in orchestrating circular value chains and find fruitful collaborations to achieve high value reuse and recycling of materials with other parties. Lastly, as previously described, demolition contractors can also use salvaged materials for own building operations.

4.4.1.6. *Engineering and Advisory Companies* - *material testing, data management, matchmaking*

Interviewee A mentions a project in which an advisory company engaged that was responsible for testing the materials and investigating whether high value reuse is possible. Interviewee C used an engineering company to test steel in a steel structure on its characteristics and to calculate the number of salvaged steel needed in a construction project. Interviewee C consulted an advisory and engineering company to inventory the potential to high value reuse and recycling for stony materials retrieved from demolition projects.

Interviewee C has also worked together with a data- and consultancy company that inventories and values the materials. This company developed a software system that supports the creation of material passports of old building stock. This further enhances the ability to register materials and to find high value reuse possibilities. Also, like previously described, one consultancy company initiated an innovative circular platform that offers a virtual marketplace, additional matchmaking consultancy and pre-demolition audits.

4.4.1.7. Independent party - connecting factor

In the pre-project phase, independent parties can be involved that steer and track the progress, being a leading mediator in the process. Interviewee D mentions a project where an independent party acted as a leader in the process, continuously ensuring progress.

4.4.1.8. Other customers: Private Individuals and Companies - purchasing role

Private individuals and private companies are buyers of salvaged building materials and components. The customer base of the marketplace of demolition contractor B currently consists solely of private individuals as they are more flexible in using secondary building products with no warranties. The customer base of the marketplace of demolition contractor C consists of companies that want to do some office refurbishment, small building contractors and. Private individuals and companies can also buy materials from wholesalers that offer refurbished products.

4.4.1.9. Producers - product take-back and recycling/refurbishment of own products or use salvaged materials in production process

Producers can have different roles. First, they can offer take-back scheme to their products. Second, producers can create new products of salvaged materials, e.g. creating wooden frames from salvaged lumber or using a portion of salvaged materials as recycled content.

4.4.1.10. Recyclers - recycling to secondary products or raw materials

Recyclers are key to transforming salvaged building materials into secondary building materials.

4.4.1.11. SROI party - providing SROI labor

For refurbishment routes, social enterprises can provide labor and social return on investment (SROI) workplaces for refurbishment activities.

4.4.1.12. Spokesman - advocacy role for tenants

In a circular project a spokesman can be present to represent the tenants' interests.

4.4.1.13. Wholesalers - retail of refurbished building materials

Wholesalers can take part in refurbishment routes to provide their infrastructure to sell refurbished salvaged materials and components. Interviewee C also explains that wholesalers can be helpful in explaining the customer demand and building material requirements.

*4.4.2. **Physical Infrastructure:** physical infrastructure (e.g. logistics, storage) that supports the ecosystem*

The physical infrastructure differs per value chain that the demolition companies have established. In the case of reuse and recycling of components via a physical marketplace, there a is a **physical location for storage and reselling.** For refurbishment value chains, the physical infrastructure of a value chain is characterized by a **refurbishment hub**. Interviewee D explains that a hub is a place where you upgrade materials. Often, the infrastructure of selling points of a wholesaler is used to sell the refurbished products. Other refurbishment infrastructure configurations are also possible. Interviewee A explains that the physical infrastructure of their wooden beam remanufacturing consists of several collection points as well. Other demolition contractors can bring suitable salvaged wood to these collection points. This wood is then transported to a refurbishment hub and these refurbished beams to a lumber factory. Here, windowpanes are created out the beams. On project level, the physical infrastructure consists of **(robotic) devices used on site**. An example mentioned by interviewee D is that they used an on-site smart crusher that deliberates sand, gravel, and cement from old concrete. These were used as the base for new concrete for dwellings close-by.

4.4.3. ***Virtual Infrastructure****: virtual infrastructure (e.g. block chain, data management) that supports the ecosystem*

Some virtual infrastructure is used by the demolition contractors to support the material inventory process or for track-and-trace purposes. For example, interviewee A uses **a tablet to inventory building materials** and upload material pictures, specifications and time and location of dismantling. Ideally, the material inventory provides a complete overview of the materials and components including size, strongness, color, ease, and costs of dismantling and possible applications. This information is then uploaded to the **online marketplace**. On the website of the platform, building contractors, architects and other potential customers can access this material information. Another example of a data management is the **use of material passports**. Interviewee C mentions their collaboration with an advisory company that creates material passports of to-be demolished buildings. These can be uploaded into the Madaster database that registers material passports of buildings in the Netherlands. Hence, material passports can also be a means to track material in new construction projects. For example, interviewee C created a material passport for a temporary modular building. After use, the temporary building will be dismantled and used elsewhere. Interviewee D also describes a case in which they used **QR-coding to track secondary and salvaged building materials applied**. However, these are no standard procedures but requested upon the client.

4.4. Cooperation

4.4.1. ***Interdependency:*** *dependency of ecosystem actors on one another*

In general, there is a high dependency on other C&D actors to fulfill circular operations. For example, wholesalers can sell refurbished products to customers, because they have an established infrastructure. Besides, architects, building contractors and other customers need **to be willing to use and purchase** refurbished, recycled and ready-to-reuse salvaged materials. Hence, there is a dependence on the **current market for salvaged materials and the possibilities for direct salvaged material application**.

There is also a dependency on **developments in other industries that produce (raw) building materials to establish high value reuse and recycling**. For example, the concrete industry is currently making demountable hollow core slabs. This will make proper dismantling and high value reuse far easier.

On project level, demolition contractors are dependent on **the client's circular ambitions.** For example, if a client obliges the use wooden window frames made of scrap wood in the final design, the architect has minor choice in not doing so. Interviewee D also mentions that in the context of direct application of salvaged materials to other projects, guarantees for immediate reuse (e.g. windowpanes) must be figured out collaboratively. Also, in terms of regulations and engineering you need each other's knowledge. Interviewee A describes that "*in terms of engineering and regulations, you have to understand what it is about, everyone has their part in this: the design engineer, the contractor, the building contractor, the client, the demolition contractor".*

Lastly, as mentioned earlier, the **time provided by the client to dismantle the old building** is also important. As B formulates it: "*if time is leading, you immediately determine to which extent materials can be harvested in a proper way. Otherwise it remains the low-hanging fruit that you can harvest and more than that*." Interviewee D also explains that salvaging building materials beyond the standard easy-to-dismantle components, strongly depends on the client wishes.

4.4.2. ***Density:*** *spatial distance in circular practices and the number of actors*

From the interview data follows that **value chains for materials are closed locally, regionally, nationally, or even internationally (only Belgium mentioned)**. For recycling routes, the actors involved are for example, a demolition contractor, a recycler, and a secondary material producer. For refurbishment routes several actors are involved e.g. wholesalers, multiple demolition contractors, multiple building contractors and SROI parties. The refurbishment chains can also be initiated by multiple parties. For example, the suspended ceiling hub was set up in partnership with around 12 other demolition contractors. In circular C&D projects this is different. As interviewee A explains: "*Typically, you only have a few companies, like 4-5. These are the demolition contractor, the client, the client for new construction, the architect, the project developer, the engineer and then you are pretty much there. So less than 10. But if you regard the number of parties that I am currently talking to boost circularity; that are more than 100*". Interviewee D explains that in circular C&D project collaborations the key actors are the client, building and demolition contractor and architect.

All interviewees prefer closing material chains locally. Interviewee C explains about the spatial scale of closing material chains: "*Preferably this is done in a very small radius around the project. Then you have a connection with the immediate environment, which is also favorable because people feel extra involved. But also, to limit transport and logistics costs and things like that.*" **The longer the value chain becomes, the less cost efficient**. Interviewee C also expresses their dependence on regional parties to realize direct material reuse: "*The moment you do not have a party that wants or can achieve it regionally, the local value chain breaks down. Then, there is often a new destination for the material to be found, but this is often of lower value than the initial set-up*".

4.4.3. ***Heterogeneity:*** *the number of different actors*

Based on the interviews, circular C&D project collaboration is characterized by a heterogenous group of actors. Interviewee B mentions the current testing ground set-up as an example to illustrate the type and number of actors. Here, they work together with a housing corporation, a building contractor, a processor of stony materials, a consultancy, an architect, an inventory agency, a communication agency and a spokesman who represents the tenants of the housing corporation. Interviewee A stressed the need of a diverse group of actors in a project to understand material and building requirements. It is more fruitful to jointly tackle the challenge of circular application of salvaged materials. To make sure this is done properly, a building contractor, design engineer, and a demolition contractor are needed to obtain the required architectural and technical knowledge. Hence, the actor group consists of a small group of diverse actors in circular C&D projects. In case of value chains, the actor group also consists of **small number of different type of actors**. However, multiple actors of the same actor type can be present. For example, a group of around 12 demolition contractors jointly operate a suspended ceilings hub.

4.4.4. ***Relationships:*** *forms in which the ecosystem actors collaborate*

On project level there are different forms of collaboration. The forms of cooperation mostly started prior to the C&D project, at the start of the project. The forms of cooperation mentioned by the interviewees were a **consortium**, a **management team** (i.e. a kind of independent jury that is present during the entire C&D process, in Dutch: regieteam), and a **construction team** (in Dutch: bouwteam). All these are forms of **early-contractor involvement collaborations** involved various actors from the C&D industry. Besides, interviewee A also mentions being part of **a consortium to produce high-quality recycled concrete** together with 4 other C&D actors.

4.4.5. ***Standardization****: activities and investments carried out to formulate industry requirements*
Regarding standardization some interviewees mention their **efforts to connect their products to existing certification schemes** for sustainable concrete and wood. Interviewees D and A seeks way to create some form of standardization for their recycled concrete production. For example, as part of the private company for concrete recycling the demolition contractor is responsible for sustaining bulk production, creating bulk capacity and certification in the concrete industry. In this regard, interviewee A tries to create a new BREEAM Super Outstanding certificate, where one of the requirements is to use concrete from concrete from concrete plants that work with base materials from old concrete. Two demolition contractors are planning to offer FSC (i.e. Forest Stewardship Council) for their refurbished wood to prove its sustainability. So, within some value chain orchestrations demolition contractors are working on certification.

4.4.6. ***Nurturing:*** *(early) investments and guidance in the ecosystem by orchestrators*
All companies actively seek collaborations with other parties to enhance their salvaged material reuse and recycling. For example, interviewee D mentions that via the **innovative circular platform** multiple demolition contractors come together to **share ideas to jointly set-up new circular value chains**. Besides, the suspended ceiling hub that they created with 11 other partners is open to join for other demolition contractors as well up until production capacity is reached.

On project level, interviewee D explains that they try to find ways to make salvaged materials more appealing to customers or clients. They try to create a **positive feeling from purchasing used salvaged materials**. Also, for direct reuse they try to make products as visually appealing as possible. Furthermore, interviewee D explains that they are **constantly searching for parties that are willing to buy the possible secondary materials** retrieved from demolishing projects.

To **foster matchmaking** on the innovative circular platform, interviewee A wants to provide digital insight into the entire demolition stock for the coming one and a half year. Also, interviewees A and C actively reached out to **producers to ideate about take-back options** for products like isolation materials. They also actively try to steer concrete industry parties towards enhanced recycling options for concrete. Interviewee C also mentions that they **discuss circular options for projects, even though the client may initially ask for traditional demolition**.

Besides also **a common goal can nurture the ecosystem**, as D explains: "*And in that way, if you together sit around the table with as a team, having the same goal, understanding the rules of the game: like, there is a flat here and we can use those materials to build something new, as it were if the existing flat is actually our store where we get our materials from, yes, then you can make a great product together. But then you jointly must focus on the right direction. And that was certainly one of the challenges at the beginning. But it worked out with the right partners. And that is what you need.*"

4.6. Capabilities

4.6.1. ***Joint Strategies & Goals****: common strategies and goals development in the ecosystem*
Common strategies and goals were only touched upon in the relation to circular C&D projects. All acknowledge that within early-contractor collaborations, **jointly engaging in a circular project and a shared ambition** is needed to succeed. For example, interviewee D stresses the importance of a **common end goal and working together towards achieving that goals** as extremely important to collaboration in circular projects and **collaboratively decide what is feasible in terms of technicality and costs**. Also, interviewee C mentions that **having the same goal** is important to collaboration in circular projects. Interviewee D provides an example of such a goal as imagining a large fence around a flat building and create new dwellings with all materials currently present.

4.6.2. ***Services/Activities Integration:*** *integration of supply chain or activities in the ecosystem*

Interviewee B has observed that some demolition contractors **share physical marketplaces**. Also, building contractors A and D both use the **same online marketplace** to market their salvaged materials. Here, the service of online offering of coming building materials is integrated. Also in **hub collaborations infrastructure is shared** (e.g. collection points and hubs) to create logistic efficiencies. Besides, there is a tendency to integrate databases to store information on materials in future demolition projects. For example, an advisory company facilitates matchmaking via uploading the material stock of upcoming demolition projects into Madaster for demolition contractor C. These databases can be used to store information of other demolition contractors as well.

4.6.3. ***Alignment:*** *alignment of goals and strategies of actors and the ecosystem*

Interviewee A mentions that every actor involved in circular C&D projects should not pursue own personal gains solely, but rather should **align personal gains with the efforts to achieve common circularity goals set**. Interviewee B stresses that pursuing solely own personal gains often reduces the quality of achieving the common goal on circularity. Also, minimizing the number of personal effort can come at the cost of achieving the most circular outcome.

4.6.4. ***Information/Data Sharing:*** *data transparency on material value and business information*

All interviewees mention that **transparency on available budgets, cost and earnings of every party involved** is helpful to succeed value chain orchestrations and circular C&D projects. Furthermore, to accelerate matchmaking of salvaged material supply and demand prior to demolition, interviewee A works towards a database that includes material information of future demolition projects.

4.6.5. ***Capabilities Sharing:*** *knowledge or expertise sharing in the ecosystem, or sharing business capabilities like supply chain management*

Working in a project team means that each party has their own role from a different angle. From the interviews follow that parties need to be **transparent and share relevant knowledge, skills, and experience**. As interviewee B formulates it: "*I think everyone, as mentioned at the beginning, should be transparent and say this my is knowledge and that I am willing to share with you, because we will ultimately benefit from it together*".

4.6.6. ***Co-creation:*** *value created by interaction between ecosystem actors*

In some circular C&D projects co-creation is observed. For example, to fulfill the aim of the client to reuse around 85% of the materials, interviewee B jointly created a plan with the building contractor. Interviewee D also mention the process of constantly searching for new ideas and elaborate on them jointly in a C&D project. This involves figuring out **how old building elements or components can be used for new (or previous) purposes**, like creating outer and inner walls from radiators or leaving part of the building in-tact. Demolition contractor A also mentions that **joint learning** can explicitly be part of the process as well.

In value chain collaborations, interviewees A and C both mention that in the process of establishing a value chain for secondary wooden beams they **jointly worked on establishing refurbishment chains with other parties**. For example, the together worked with a wholesaler and a SROI refurbishment party on how to create a product line for salvaged wooden beams. Another example is the collaboration of demolition contractor A with a steel factory to explore how to steel beams can be refurbished. They jointly explore how refurbished beams can fulfill building requirements and become a price-competitive product to their primary counterpart.

4.6.7. ***Joint Problem Solving:*** *jointly tackling of problems in the ecosystem*

Interviewee C mentions that in circular projects circularity is the shared ambition. This automatically results in that **each problem is a shared problem in a circular C&D project**. For example, if they need more time in a project to retrieve certain elements from the building, they jointly must find a solution to do so. Interviewee D also explains that within such a C&D project collaboration you **jointly make architectonic and cost considerations**. Also, the guarantees must be worked out reciprocally between the C&D actors in the project.

Besides, this also can involve **joint problem solving on hampering regulations**. For example, reusing salvaged doors directly is currently not compatible with the regulations in Bouwbesluit for new constructions, but it is for renovation projects. Upon this, they together agreed with a municipality to turn a new construction project into renovation project. On component level, interviewee A they jointly solved the problem on how to recover concrete hollow core slab floors.

4.6.8. ***Trial-and-error:*** *process of trial-and-error to achieve fruitful circular operations in the ecosystem*

Orchestrating new circular value chains and circular collaborations show trial-and-error patterns. As interviewee D mentions in the context of their early investment in a debris crusher: "*What I often find is that if you start doing certain things and dare to invest, you go on continuously, you get a kind of development process*". Also interviewee A, first trialed high value recycling of concrete in one project and is now going to be up-scaled. On project level, interviewee D argues that reusing or recycling certain elements can be trialed as well, but only setting up these projects for one dwelling is too costly. However, if **one dwelling is the experiment that acts as the base to built other dwellings circular** then it is already more feasible to do so. Besides **learnings can be used for other projects as well**.

Also, value chains seem to adapt by a form of trial-and-error. Interviewee A explains that **refurbishment chains are first a trialed, involving only partners**. If it works out well, they seek further collaborations and share logistics and capabilities amongst interested parties. Besides, interviewee A mentions the **continuing process of environmental impact minimalization** after a chain is established.

4.6.9. ***Commitment:*** *commitment of ecosystem actors to engage in circular operations*

Client commitment is mostly present at clients that specifically ask for a circular approach of a demolition (and construction) project. **Especially, governmental bodies increasingly include circularity criteria in their tenders**. This can even imply that the client obliges the use of circular building materials instead of their less expensive primary counterpart. **Commitment of the client is important since most clients tends to prefer to focus only on lowest costs.** As B formulates it "*we currently often face the problem that one says: great, reuse what can be reuse, as long as it does not cost me more money*".

Client commitment also involves **investor commitment**, as investors can also be clients. Interviewee A exemplifies: "*a real estate owner that need to create 600 dwellings still choses primary frame wood then we will not solve the wood waste problem. He rather needs to dare to chose for the secondary frame wood that we retrieve from buildings*". Commitment from the client is really needed as interviewee D explains: "*... if a client says I want it as inexpensively as possible, unfortunately that does not always fit to do it as circularly as possible*". Besides, **the investor or client needs to be willing to engage in the collaborative trajectory needed** and be enthusiastic to explore and implement circular strategies to salvaged materials. Lastly, investors and clients also need to **prefer the (more expensive) circular building materials**.

Commitment of building contractors to build with secondary building materials is also highly needed. This depends on the contractor's mindset. Interviewee D explains that some building contractors really want to have certificates on building materials, whereas others are fine with evidence that the secondary building material fulfills all requirements. As he exemplifies: "*if a building contractor says: I want to have frames that have exactly that and that size and they must comply to this and this. Then it probably won't work out because it doesn't work that way; because it may be that the frames are a larger or smaller size and need a little more attention or need to be updated a bit to be able to process them correctly to get the same end-product*." Interviewees A and C mention that building contractors often find it tensive to work with salvaged materials. They often say that they cannot make the calculations. To overcome this problem interviewee A explains that they had to carry out the building contractor part themselves or hire freelancers. To the experience of interviewee C, large building contractors are generally not intrinsically motivated to build circular and predominantly prefer new building materials with recycled content rather than salvaged building components. Customer commitment of private parties and small contractors is present upon **intrinsic motivations or enthusiasm about constructing with salvaged materials**. **Besides architects need to include secondary materials in their designs** as well.

Interviewee C also observes **commitment from building material producers** as some are reconsidering their value chains with respect to circularity. Even concrete producers that initially held back from any circularity developments slowly embrace circular practices, like increased use of secondary concrete as gravel replacement.

Lastly, in case refurbishment routes that deliver to wholesalers, the **commitment of wholesalers** to engage in such a collaboration is highly necessary.

*4.6.10. **Adaptation**: adaptations of ecosystem actors to the circular operations in the ecosystem*

The number of openness needed to pursue circularity goals requires some adaptation of all parties involved. Working towards circularity, disposes traditional ways of working that are characterized as "the linear model" where only a client-contractor relationship is present. According to interviewee D you have to sit together and ideate about possible options for reuse and break the non-collaborative traditional mindset. On project level, interviewee A mentions that parties had **to get used to providing openness about prices and techniques on how to achieve high value reuse and recycling**. This also creates an environment of trust, collaboration and common understanding. **Gaining trust in each other ('s intentions)** is regarded as particularly important in these processes by interviewees A and C.

Parties involved in the circular project need to be more flexible than in traditional projects. As interviewee A mentions: "*Everything around building materials is surrounded by rules and guarantees, the client can also go beyond rules and guarantees and just say: we use this components when it is approved by a pressure test*". In this regard, interviewee C has the experience that smaller parties generally tend to be more flexible as they can switch more easily and are generally more intrinsically motivated. Interviewee D mentions that there is a different mindset needed among employees as well, as everyone involved needs to **be(come) enthusiastic and feels like investing time and effort** accomplish the circularity goals set.

*4.6.11. **Attitudes:** attitude changes required to fulfill circular operations in the ecosystem*

All interviewees that **like-mindedness** regarding the importance of circularity is needed. As interviewee C states: "*…to make projects that are just a little bit more special than other projects, you all must be a bitsy crazy, because that takes more time, more energy, more irritation. So, you can't escape doing that with like-minded people*". A cooperative attitude that is considered essential by all.

This also involves an attitude in which **one should not strive for own personal gains**. As interviewee C formulates it: "*when I think about attitude: particularly flexible and open and taking on the challenge together with a form of collectivity, without any kind of hostility like, wait a minute, I think you earn a euro more in this situation…*". As interviewee A illustrates: "*the entire chain must provide openness and must dare to watch over each other shoulders*". Clients also require a looser or more daring approach towards applying salvaged materials, such that they may not be hampered so much by compliance. After all we are part of a transition, explains interviewee A.

4.7. Change

4.7.1. ***Anticipated Role Change:*** *role change required of ecosystem actors to fulfill circular operations in the ecosystem*

Interviewee D expects to take an a**ctive role of demolition contractors in finding solutions to circular material processing.** As interviewee D explains: "*the modern demolition contractor, so to speak, also get the secondary activities of processing or processing the material and the correct sale thereof*". This will involve orchestrating circular value chains. All interviewees also see **an advisory role for the demolition contractor**, as they understand best how to create a building for future dismantling. Furthermore, interviewee B explains that demolition contractors have the knowledge and skills on how to acquire materials as well as the knowledge on possibilities for reuse and recycling. Interviewee A summarizes these two roles in the following quote: "*Whatever building or object we talk about it should be disassembled and reassembled, that is like managing a material depot. This requires material expertise and methods on how to disassemble and reassemble, that is a profession, besides you have to do something with storage, something with transport, with refurbishment; that we clearly see as part of our domain; that building materials retrieved have to be reworked by hand or by robotic operations*".

Interviewee C even thinks that demolition contractors will be **hourly paid for the practice of dismantling in the future.** It may be that most products (e.g. installations, elevators, facade) are leased and still in ownership of the producer. Previously, when they received the building's keys and everything present in the building was considered the ownership of the demolition contractor, whereas this is not the case anymore if more if products and components are leased.

Lastly, interviewee A mentioned the **potential role of banks as they can provide loans to the building rather than the owner**. In that case, the monthly payment will be lower in case of sustainable material use even if the initial price of the sustainable building products may be higher. The monthly fee for sustainable building materials is lower, due to the value retainment over the circular product's life cycle.

4.7.2. ***Anticipated Change in Collaboration:*** *collaboration change between ecosystem actors to fulfill circular operations in the ecosystem*

All interviewees mention a collaboration change on project level from the traditional linear model to **a model that allows for early contractor involvement in the beginning of the circular construction and demolition project**. To accelerate salvaged material matchmaking, interviewees B and D indicate that it would be best if clients consider their own future construction portfolio for applying salvaged materials. As interviewee D formulates it: "*Understanding it has to be demolished; then you also like to discuss with the housing corporation what do you want to rebuild at that location or what do you want to rebuild elsewhere in your portfolio and what elements can we reuse that are released on another project*." There are no shorter communication lines than reusing elements within your own organization.

4.7.3. ***Process Change:*** *changes required to the business processes in the ecosystem to make it more circular*

On refurbishment level, **value chains require new circular business process changes** to become more circular. For example, instead of processing wooden beams to chipboards, they are refurbished. The same counts for steal beams that have standard measurements, which can be refurbished and resold instead of recycled. A step further is that these hubs are universally used by several (building and) demolition contractors.

Also, the process of demolition changes, such that **demolition practices are tailored to careful dismantling of components and materials**. This process will also change upon the growing **application of easy-to-dismantle products**, like click-in window frames and easy dismantlable hollow core slab floors. Ideally, all some of the components are also returned to the producers.

All companies anticipate that **virtual registering materials of to-be demolished buildings** is needed in the process of matching demand to supply. If matchmaking of salvaged materials to new construction projects increases, the number of high value reuse and recycling is expected to increase as well. With respect to value chain development, three companies are already working on increasing the number of recycled concrete. This will enhance the amount of high value recycling.

4.7.4. ***Competitive Advantage:*** *competitive advantages that make operating in the ecosystem more preferable*

All demolition contractors experience competitive advantages from their **learnings in circular projects and their orchestrated circular value chains. These can help to win tenders and attract parties that are affiliated with sustainability like municipalities, housing corporations, universities**. Interviewee D illustrates this by saying "*Certain clients become enthusiastic about our way of working on certain projects and that gives a lot of people a more enthusiastic feeling, seeing: they consciously deal with the materials, they are consciously with the future, they are innovative"*.

4.7.5. ***Strategic Advantage:*** *expected future advantages that makes operating in an ecosystem more preferable*

All demolition contractors mention that they experience strategic advantages. They **anticipate on increasing future demand for circular materials (e.g. only circularity tenders by 2030). Especially, when future regulations will be effective this will improve the business case (e.g. carbon tax).**

4.7.6. ***Shared Advantages/Mutual Benefits:*** *benefits that are realized more than one participant in the ecosystem*

There are also mutual advantages present when it comes to collaborating in hubs. For example, in the suspended ceiling **hub all participants receive a financial advantage,** as they avoid regular disposal costs. Also, **within a value chain each actor gets a fair share**. As interviewee A explains in case profits are made this will be fairly shared between the wholesaler and participating demolition contractors.

4.8. Key insights on the 6C-dimensions

This summary offers the key insights that resulted from this chapter following the core 6C-framwork structure of context, configurations, construct, cooperation, capabilities and change. Appendix E includes a table that summarizes all findings from the case study research in all 1st- order categories.

4.8.1. ***Context:*** *environmental features of the circular supply network*

Over the past years, clients with circularity ambitions have slowly emerged. These clients are especially governmental bodies that strive towards achieving the circular ambition of becoming fully circular by 2050. The built environment consists of different types of buildings that all have different building materials applied. The bulk of the material applied is concrete. The number of high value recycling and reuse of building materials achieved by the demolition contractors, dependent strongly per project, but in general ranges between 1-20%. There are also examples of projects that reached high levels of reused salvaged materials (e.g. 98%).

All demolition contractors have standard dismantling approaches to easy-to-dismantle components that can be resold or refurbished. Generally, selective dismantling of building elements and components cost more time, effort, and manpower than regular demolition. Because of this, more than standard dismantling practices are often only achieved upon the client wishes (e.g. by early-contractor collaborations in building teams or testing ground set-ups). In case of direct application of salvaged building materials to a (local) construction project, cross-disciplinary technical and regulatory knowledge is needed from at least the architect, building contractor and demolition contractor.

In case there is no direct application of salvaged materials to a (local) construction project, demolition contractors orchestrate value chains for resell, refurbishment and high value reuse and recycling. several routes to high value reuse and recycling or constructed for different components (e.g. suspended ceilings, wooden beams) and materials (e.g. gypsum and concrete). Several new routes to high value reuse and recycling are currently explored by the companies (e.g. sanitary, other wood types, carpet tiles, masonry). The traditional mindset of demolition contractors is rather competitive, but there is an increased cooperation and willingness to exchange ideas on circular practices between C&D actors observed over the past years. All demolition contractors in this study have the intrinsic logic that high value recovering of building materials can provide environmental and societal benefits and solve scarcity issues. Besides, investing in high value recovery can provide financial benefits and can become especially beneficial on the long-term when certain environmental regulations like carbon taxes or mandatory MPG calculations of building materials. In this regard, they strive to minimize waste and the number of new materials applied in construction projects.

Regarding barriers, salvaged and secondary building materials compete with their often low-priced, guaranteed and qualified primary counterparts. It is difficult to provide certificates and guarantees to salvaged building materials, as you may not discern the material specifics and lifetime. On physical marketplaces, salvaged building materials are therefore mostly sold without guarantees, attracting predominantly a customer base of small building contractors, small architects and some private individuals or companies that use it for home or office improvements. There is also low transparency on the demand for salvaged materials, as the market is rather opaque. Resultingly, matching supply and demand of salvaged building materials is rather difficult, as current supply of certain salvaged building materials and components may surpass current demand. Or the other way around: supply may be insufficient to meet (immediate) demand. Besides, cost and environmental reasoning excludes sales that involve long-distance transport. The lack of universal used (grounded) standards that signal the circularity grade and/or environmental impact reduction of secondary building materials creates difficulties to signal the environmental impact to customers in a universal and comparable way. Lastly, too specific quality criteria on circularity in tender requirements may demotivate achieving higher ambitions than those set.

4.8.2. ***Configuration:*** *activities in circular supply network and how these form configuration patterns*

All demolition contractors orchestrated several value chains and engaged in early-contractor collaborations on project scale, applying secondary materials from old demolition stock to new construction projects. This results in the observation of two main configuration patterns: orchestrated value chains to resell salvaged materials for reuse (e.g. at online marketplaces) or refurbish (e.g. wooden beam refurbishment) and those that concern direct application of salvaged materials in a new construction project. The salvaged materials themselves are free of charge as retrieval from the building (and possible storage or refurbishment) is costly. Earnings are retrieved either from saving material costs in case salvaged materials are directly applied to another project, or from reselling or selling refurbished building materials. Value creations mentioned in value chain orchestrations are social value (i.e. in case SROI labor is used for refurbishment practices) and environmental value by avoiding primary material use and prolonging material use. Also, esthetic value was mentioned as another type of value creation. This is value is created for those who particularly appreciate the (visual) application of salvaged material application to new buildings.

4.8.3. ***Construct:*** *activities in circular supply network and how these form configuration patterns*

The actor roles differ per value chain or project collaboration. On project level, the core actors are: the architect that uses salvaged materials from the old building stock in the design; the building contractor that performs calculations on the secondary materials needed for new construction; the client that provides the project with circular ambitions, and the demolition contractor compiles an inventory of salvaged materials in the old building stock, selectively dismantles materials from the building stock and provides advice for design for deconstruction. In addition to this core actors, academia could provide research support, engineering and advisory companies could provide material testing and aid material data management (e.g. provide material passports) to facilitate matchmaking of supply and demand. Furthermore, an independent party can have a connecting, leading or mediating role to the project. Lastly, a spokesman can be present that advocates the interests of the future tenants in the project.

In some refurbishment routes found, building contractors cooperate as a customer and logistic partner in refurbishment hubs. In all hubs, SROI labor was provided by social enterprises. In the case of no direct connection to building contractors, wholesalers retail the refurbished building materials in their stores. For recycling, refurbishment and reuse orchestrated by building material producers, producers have take-back schemes. To achieve high value recycling, demolition contractors themselves or recyclers produce clean material fractions that are then transported to secondary building material producers.

For marketplaces that solely consist of an online infrastructure, material inventories are uploaded and offered on an online platform prior to dismantling. They for example register materials specifications, release time, date and location. This is currently achieved by demolition contractors themselves and/or advisory and engineering companies that facilitate the platform (and subsequent matchmaking). In the case of projects, data management on materials is conducted upon request of the client e.g. material track-and-trace via QR-coding or material passports.\

4.8.4. ***Cooperation:*** *activities in circular supply network and how these form configuration patterns*

There is a certain interdependency observed between the value chain orchestrations and the customers' and building contractors' willingness-to-purchase. A refurbishment chain is terminated if there are too few customers for the secondary building components or materials. Besides, developments in other industries that produce building materials and components highly influence the number of high value reuse and recycling that can be reached. For example, if hollow slab floor producers produce demountable hollow slab floors, this allows for easy-dismantling and reuse. Also, if producers adopt take-back schemes they make sure that refurbishment, reuse, or recycling take place. On project level, the number of high value reuse and recycling largely depends on the client's circular ambitions and the time provided by the client for pre-demolition audits and pre-matchmaking to construction projects or finding customers for the salvaged materials. Having a common goal to work towards, acts as a driving force that nurtures the project ecosystem.

With respect to the density, materials loops are closed locally, regionally, nationally, or even internationally (only Belgium was mentioned). They are preferable closed as local as possible since this is most (transport) cost and environmentally efficient. With respect to heterogeneity, at least four actor roles are present in circular C&D projects: the client, demolition contractor, architect and building contractor. This can also be extended to multiple other parties joining (e.g. spokesman, advisory company), but less than 10 actors are present in total. In value chain orchestrations at least two or three actors are involved, i.e. demolition contractor company & wholesaler or reseller or demolition contractor and building contractor or demolition contractor, recycler, and producer. However, to operate hubs more actors can join. For example, around twelve demolition contractors joined as partners in the suspended ceiling hub.

4.8.5. ***Capabilities:*** *capabilities used in the circular supply network*

On project level, having a common end goal and as well as collaboratively deciding what is feasible in terms of technicality, costs, and budget is very important to success. In value chains, virtual (e.g. online marketplaces) and physical infrastructure (e.g. physical marketplaces) are sometimes shared. For example. online platforms for selling salvaged materials or sharing the logistics of refurbishment hubs. In the latter, the existing infrastructure of wholesalers' stores is often used. Refurbishment chain development shows a pattern of trial-and- error: first, being piloted and involving only initiating parties. Later, opened to other parties to join and other optimizations (e.g. transport electrification), if the value chain is successful.

Furthermore, it is important to align personal interests to the common interest of achieving circularity goals. This for example includes, aligning personal effort with (extra) common effort that is needed to achieve circularity goals set. To do so, it was regarded as helpful to have transparency on available budgets, costs, and earnings of all circular activities of all actors involved. In addition, sharing information about barriers and progress was also attributive, as well as sharing relevant knowledge (e.g. technical knowledge, guarantees), skills and experiences. This also entails jointly making architectonic and cost considerations and solving problems related to hampering regulations, salvaged material or component guarantees and time provided by the client. Also, joint efforts are needed to establish refurbishment chains. The circular solutions found for on-site salvaged building material applications are often part of a co-creative, joint effort and joint learning process. Learnings from trialing circular operations in previous projects can also be used to optimize circular operations in later (larger) projects.

Within projects and value chain establishment an open, flexible, cooperative, and transparent attitude is required. This is not a standard practice in the C&D environment. Actors involved therefore need to adapt to provide openness about prices and techniques and gain trust in each other and each other's intentions. They also need to be more flexible than in traditional projects and be(come) enthusiastic. This cannot exist without commitment of all parties involved to engage in these intensive collaborations in comparison to traditional projects.

4.8.6. ***Change:*** *the process of shifting from one supply network to a circular supply network*

All interviewees expect that the emerging trend of circularity in the built environment will continue. This will imply an increase in dismantling practices with an active role of demolition contractors in finding and developing solutions to circular material processing, but also advising C&D projects on how to build (for deconstruction), inventory materials in the current building stock and aid to determine the potential applications of the salvaged materials available. Interviewee A also mentioned the potential role for banks to provide loans to the building rather than to the owner as this can stimulate applying circular building materials and components.

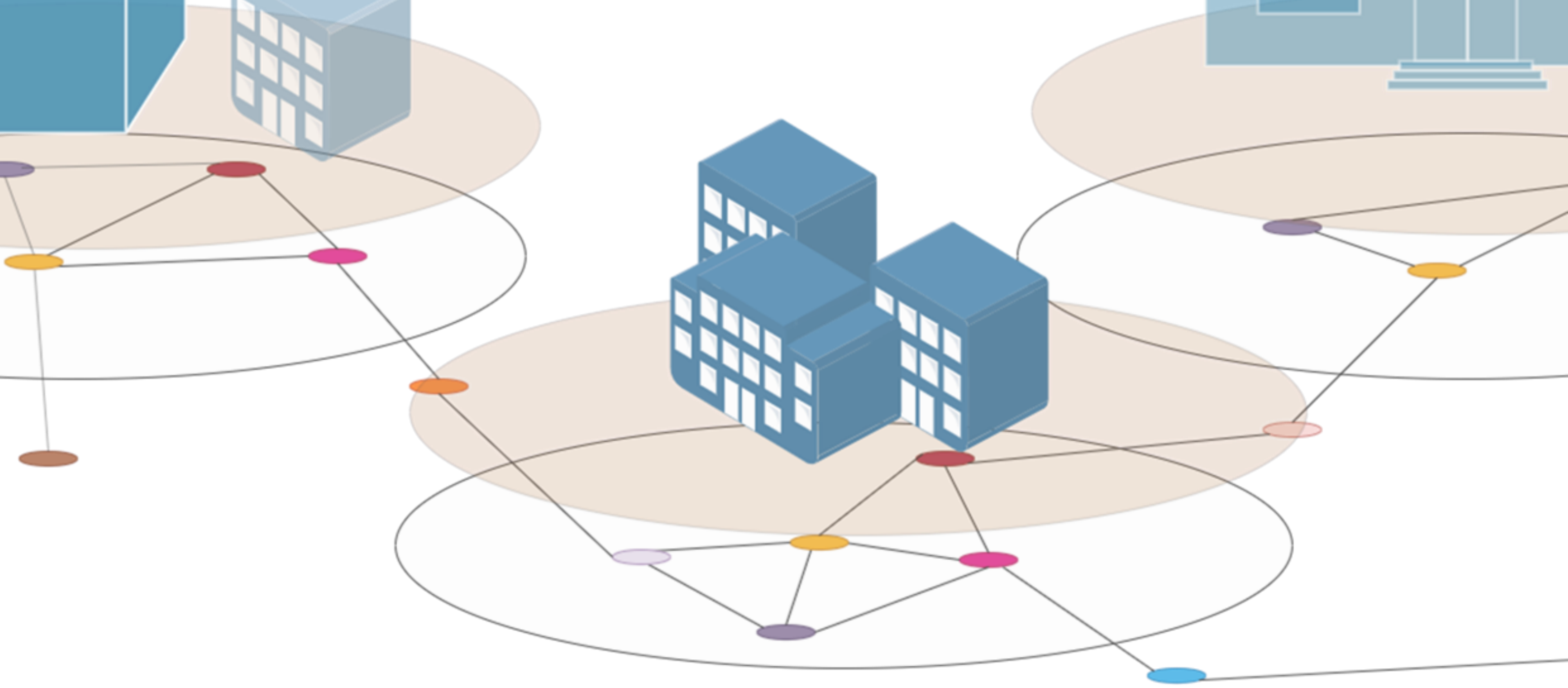
They also expect more early contractor involvement collaboration in the beginning of the circular C&D project and more close collaboration with clients and other C&D for matchmaking purposes. Current value chains that do not include high value reuse and recycling, require business process changes to enhance the value chain. In addition, further tailoring of careful dismantling practices (e.g. by robotic operations) is also expected to continue and to improve increase efficiency.

Besides, demolition contractors use their experience from circular C&D projects and value chain orchestrations in offerings to clients or for further value chains development. Lessons learned together are valuable to future tender applications. Besides, it attracts parties and potential clients who are also affiliated with sustainability like municipalities, housing corporations, universities. (Shared) investments in circularity may result in future returns on investment, as some anticipated regulations that will improve the business case (e.g. carbon tax) will likely to be effective in the near future.

As this chapter is very lengthy and information dense, Figure 4 displays a very compact overview of the results found in this chapter.

Context	Change
• there is an increasing interest for circularity in the built environment from clients and other C&D actors • circular projects demand selective dismantling, which cost more time, effort and manpower • currently the highest achievable is that circular projects and circular value chains break-even	• more early-contractor involvement in future projects • moving from demolishing to dismantling buildings • virtual registering of to-be demolished building stock • more circular handling of salvaged materials by increased circular value chains and projects • engaging in circularity is (mutual) benificial from strategic and competitive perspectives
Construct	**Configuration**
• small diverse group of actors in projects (± 4-7) • initial small group of actors (± 2-3) in value chains • virtual support of online accessible salvaged material marketplace • QR-codes and material passports to track materials are used upon client request • storage is used in case of no direct application of the salvaged materials to another project	• two main configuration patterns: salvaged materials are either (directly) applied to a (construction or renovation) project or processed in value chains • earnings are retrieved from either saving material costs or from (re)selling (refurbished) salvaged materials • often circular processes include environment and social value are creation as well
Cooperation	**Capabilities**
• collaboration between demoliton (and building contractors) to create economies of scale • early-contractor involvement in projects (e.g. construction or management team) • connecting circular processed salvaged materials to existing certification schemes • nurturing by exploring opportunities with clients to include circularity in their C&D projects	• joint discussions on economic and technical feasibility and jointly setting goals • integration of services (e.g. one (online) market-place used by multiple C&D actors) • (personal vs. common) goals and effort alignment (e.g. work with open budgetting in order to do so) • knowledge, information and experience sharing • daring, open, flexible and cooperative attitude

Figure 4. Compact overview of the 6C's that followed from the main results in this chapter



5.

Discussion

Reflections on results

5. **Discussion:** reflections on results

This chapter entails the explanation, interpretation, and implications of the results. This includes a discussion of results as a contribution to academic literature and their practical relevance. To verify main findings and the practical relevance, 3 consultants and 1 architect were interviewed. One of the sections is devoted to their input.

5.1. Reflections on barriers and enablers

Regarding barriers, Kok & Koning (2019) mention that high value recovery does not always cover the additional costs for dismantling and refurbishment. This was found in the results as well: one of the physical marketplaces hardly breaks-even and the wood refurbishment hub of demolition contractor C is currently not profitable. However, all demolition contractors still continue participating in circular projects and creating circular value chains, because there are certain advantages. For example, circular project participations and circular value chain orchestrations create a competitive and strategic advantage for the demolition contractor (and other ecosystem actors) involved. For example, in case circularity is highly valued in future tenders, they can offer better proposals. They can also use their circular achievements for branding and attracting new clients. Besides, circular value chains provide (more) economic benefits when future environmental legislation (e.g. carbon tax take effect. What also hampers finding high value alternatives for low value waste handling is the fact that current buildings are not made to dismantle. Not everything is worth recovering if its initial value is low. Components can be glued and purred together such that high value reuse is currently not possible. This is line with the findings of Ruiz et al (2020) that found that circular economy strategies are not applied to most existing buildings (Ruiz et al., 2020). Besides, investors and clients are generally mostly interested in the lowest price in the fastest time and well-acknowledged standards and certificates. Therefore, there is a tendency observed in the results that products, components, or materials form new value chain configurations (e.g. wood refurbishment, 100% concrete recycling) try to be assured by existing schemes and certificates.

Ghaffar et al. (2020) mention that high value reuse or recycling of salvaged building materials, demand more time. The current results confirm that proper retrieval of salvaged materials from old building stock is more time-consuming and costly than regular practice. Besides, there can also be additional costs involved for transport and possible storage. However, it helps if there is a(n) (immediate) connection to another (local) project to apply the salvaged materials or components. This can even lead to time and cost savings. For example, in one case concrete floor slabs were immediately applied in another near construction project. This only took a few days of crane and a few kilometers of transport. Besides, this avoided the more time-consuming process of crushing and refining the concrete floor slabs.

Ghaffar et al. (2020) also identified logistics to be a barrier to high value processing of C&D waste. Regarding direct use of salvaged building materials, this was acknowledged as a barrier as well. A focus on offering local solutions can overcome this problem. For example, interviewee C mentioned the possibility to bulk salvaged materials locally, with other local demolition contractors, to enhance logistics. Another solution are local refurbishment hubs that can serve as a logistic center where local building contractors can immediately transport and use the refurbished building materials. This reduces the transport needed. To overcome the barrier of emissions emitted during transport, diesel transport can be replaced by electric transport that runs on electricity from renewable resources.

Another problem mentioned by Ghaffar et al. (2020) was that information about the material composition and in-use lifetime that may be unavailable and require testing, which can increase the costs of recovery. Indeed, if testing is required, this adds additional costs. However, subsidies can help to create a viable business case. In case of offering salvaged building materials and components at physical marketplaces, currently no product guarantees are provided because of unknown material specifics and in-use lifetime. However, guarantees are provided in case of refurbishment of salvaged materials.

The presence of customers of salvaged or secondary building materials was regarded as particularly important to make a business case. On the one hand, there is the importance of the network of the demolition contractor to resell materials or offer them via marketplaces or refurbish them in hubs. On the other, clients in projects also need to foster direct application of salvaged materials. Clients need to have circular ambitions to apply secondary and salvaged building materials into their projects. Hence, they should not consider time and costs solely as tender criteria. To reduce the costs from the dismantling and refurbishment practices, replacing labor by capital (e.g. robotic operations) would be helpful. However, this can come at the expense of the social value creation in case of the current use of SROI labor.

Regarding enablers, Leising et al. (2018) argue that circular construction projects should start with clear circular vision with ambitions, executed by a multidisciplinary team with a system scan for value creation for all stakeholders involved. Indeed, all interviewees consider working towards a jointly set goals as particularly helpful to succeed a circular C&D project. Besides, they all agree that working with open budgets and openly sharing information on each other's costs and earnings is especially helpful. Leising et al. (2018) also proposed that salvaged materials can be repurposed via brokerage by a marketplace or by take-back schemes supported by suppliers of short-lived products. One interviewee indeed regarded producer take-back schemes to be helpful to establishing high value reuse and recycling of secondary building materials. Online marketplaces are especially useful when they foster direct demand of salvaged materials at the time of dismantling. Additionally, the refurbishment of salvaged materials in hubs can be added to the suggestions of Leising et al. (2018).

For developing circular value chains in the building industry, stakeholder collaboration is also seen as highly important (Adams et al., 2016; Leising et al., 2018). Collaboration was indeed regarded as notably important to circular C&D projects and the establishment of circular value chains. In case of circular C&D projects for example, demolition contractors can provide useful advice on what and how to apply salvaged building materials. Subsequently, early-contractor involvement is very suitable for circular projects (e.g. in a regie team or construction team).

Likewise, the findings of Ghaffar et al. (2020) the interviewees acknowledge that pre-demolition site assessments or audits are needed to thoroughly examine the potential for reuse, recycling, and subsequent reselling of the building materials in the old building stock. However, to do so the client need to be willing to provide sufficient time for a proper inventory. For example, if sufficient time is provided one can also examine the isolation material applied in the interior walls.

Only two governmental incentives that stimulates circular practices in the built environment were observed in this study: subsidies (e.g. for material testing) and an increase in quality criteria on circularity in tenders from governmental bodies. Also, the likelihood of future governmental regulations (e.g. carbon tax) taking effect, steers demolition contractors to experiment with circularity.

5.2. Reflections on circular business ecosystem theory

Regarding drivers, a mix of inner and external drivers were present to reconfiguring value chains to more circular ones and to engage in circular projects. The small but increasing trend of clients (especially governmental bodies) with circular ambitions was mentioned by interviewees as a reason to engage in circular practices. Parida & Wincent (2019) found the external environment and resource scarcity as a driver towards establishing circular business ecosystems. Resource scarcity was indeed mentioned by the interviewee. The **enhanced profitability, cost efficiencies** and **better customer offerings** that were mentioned by Gupta et al. (2019) were not directly mentioned as most circular operations are more cost intensive and are yet difficult to break-even. However, interviewees do believe that on the long term (in case of presence of certain regulations) these circular operations will become profitable.

Lacy et al., (2020, p. 295) mention that **regulations** can impose barriers to adopt circular practices. The results showed that the regulatory environment (e.g. certification is needed, Bouwbesluit can hamper direct reuse) was indeed considered as barrier. However, also more business environment specific barriers were mentioned, like the mismatch between supply and the currently opaque demand for salvaged materials.

Besides, the supportive **virtual infrastructure** was found in this study to be mainly the use of online marketplaces to offer (future freed) salvaged materials. The tracking of materials was sometimes applied to projects e.g. by applying QR-codes to salvaged materials or material passports. But this was only conducted upon the clients' request and no standard procedure. Furthermore, some building contractors explore the opportunities of uploading current building stock in databases like Madaster. Regarding the actor balance, collaborating actor groups in circular projects and value chains are heterogenous group of actors likewise the findings of Tate et al. (2020).

Furthermore, especially early-contractor involvement in circular C&D projects show commonalities literature review finding on circular business ecosystems. These entail for example the presence **commitment, information, knowledge and expertise sharing, co-creation and joint problem solving** that were part of the capabilities found in the literature review. All interviewees mentioned **strategic** (e.g. anticipating towards a changing regulatory environment) and **competitive advantages** (e.g. gaining expertise in providing circular solutions) that resulted from these C&D projects. From the interviews further followed that early-contractor involvement with circular ambitions indeed **enhances client offerings** and decreases the primary resources used in the project. **Trust and cohesion** are regarded as important, but also **openness and flexibility** as circular C&D project require more time and effort than regular projects. Besides, **having common strategies and goals** (as mentioned by Konietzko et al., 2020a) in a project is particularly important to succeed as well.

Lastly, Parida et al. (2019) found **give and take rules** and **relational interdependence** (e.g. profit sharing and purchasing arrangements, granted exclusivity, risk division) and executing a **risk-benefit analysis** as negotiation mechanisms to partner inclusion in circular business ecosystems. Indeed, every collaboration showed dependencies on each other capabilities and knowledge to succeed.

5.3. Reflections with practitioners

Several experts in the field of circularity in the built environment were asked to reflect on the results and findings of this research and the practical value of a circular business ecosystem analysis. This concerned 1 small architect that designs with circular materials, 2 consultants that have worked on circular building projects, 1 consultant that is part of the innovative circular platform that hosts the online marketplace used by demolition contractor A and D, and 1 accelerator of circular building practices. All interviews lasted 60-90 minutes.

From the discussions followed seven main attributions. First, all experts provided personal experiences regarding the business environment. Second, all stressed the importance of the client's wishes regarding the application of secondary materials. Third, the consultant that is part of the innovative circular platform elaborated on value chain orchestrations of demolition contractors. Fifth, all experts elaborated on how direct application of salvaged building materials could be accelerated by early-contractor involvement and an online in-stock building material and components database. Sixth, several consultants elaborated on the business model for direct application of building materials in (local) construction projects. Last, all experts gave their opinions on the practical value of a circular business ecosystem analysis.

5.3.1. Reflections on the business environment regarding circularity in the built environment

All experts agree that accomplishing circularity in the built environment can only be achieved in cooperation with value chain partners. The overall observed trend is that the focus on **circularity in the built environment is growing**. Especially in governmental projects circularity increasingly plays a role in tenders. In practice, experience is often considered as criteria in tenders as well. This is regarded as stimulating factor for parties to gain experience in the field of circularity. However, the number of circular projects is still considerably small. For example, the architect mentions that to his experience only 5% of private sector clients have circular requirements.

There are certainly difficulties in practice that hamper the application of salvaged building materials and components. The architect that currently predominantly conducts private projects like renovation or home improvements, experiences that he is mainly dependent on the infrastructure of local demolition contractors. If a complete local organization of circular value chains for salvaged materials existed (e.g. local refurbishment and storage of materials), this would open up more possibilities to local reuse and recycling. Unfortunately, this is not the case in his experience. Another problem acknowledged by all experts is the **mismatch in supply and demand.** Currently, it is **too opaque what and when certain building materials** are released from a building.

As enablers, **circular products, components or materials from old building stock need to become cheaper** or the **client must set more circular requirements**. In addition, one consultant mentions that **investment decisions based on Total Cost of Ownership** (investment + management & maintenance + end-of-life) would promote the choice for circular materials. In addition, the governmental financial incentives **carbon tax and reduced labor costs** were mentioned.

5.3.2. The importance of the client's wishes regarding the application of secondary materials

All experts acknowledge\ that there is a vast dependency on the client's wishes to engage in an ambitious circular project. In this regard, the **client should actively strive toward hiring parties (or consortia) that are concerned with obtaining the highest possible residual value of the building**. This can also include that the client demands more collaboration throughout the project. Besides, it would be particularly helpful if **clients (and building contractors) have a certain flexibility towards the salvaged materials' design** (e.g. color, size, measurements) and the **time of arrival of salvaged building materials on-site.**

5.3.3. Value chain orchestration of demolition contractors

To overcome the barrier of mismatch in demand and supply, commonly retrieved salvaged building materials and components can find their way into refurbishment chains, **creating more continuous stock at the wholesaler**. The consultant of the innovative circular platform has experienced that setting up a refurbishment chain is like setting new kind of ecosystem with changing actor roles. First, demolishing becomes dismantling, then transport must be arranged, then refurbishment parties are needed etc. Subsequently, these hubs are used by several demolition contractors who rent storage or supply raw materials for refurbishment. Earnings are made when the proceeds at the wholesaler yield more than the costs incurred. The **advantage of working together in these value chains are the resulting economies of scale**.

The consultant also mentions that it is rather unique that demolition contractors work together and trust each other. Traditionally, every demolition contractor has its own sales channels, for wood and steel, for example. In this way they avoid high waste disposal costs. These resell routes lead to eventually to buyers who process or resell the salvaged building materials. These final applications can also be lower-value reuse or recycling. In practice, **lower-value options are often chosen because of budget and time constraints**.

5.3.4. *Early-contractor involvement to accelerate direct application of salvaged building materials and components in projects*

All experts have experienced or acknowledge the value of **early-contractor involvement in the beginning of a circular construction project**. For the time being, working in intensive partnerships will be necessary in circular projects to learn and to understand each other. This can become less of an intensive collaboration over time when there is some sort of standard working method on how to approach circular projects. One consultant argues from experience that working more together in a circular project - especially by involving relevant actors at the start of the project - will certainly improve achieving circularity goals.

For example, construction teams could favor a project because **it contains commitment and trust elements**. The idea behind a construction team is that executing parties are involved in the beginning of a project. The project ambitions are less defined in advance. Within a construction team, ambitions are jointly formulated and discussed. **All parties have a stake in succeeding the project and hence also a real interest in achieving goals set**. For example, it is beneficial to the demolition contractor involved to deliver as much of salvaged building materials and components from own demolition projects.

Besides, in a construction team collaboration, the possibilities, and opportunities of **what is financially, budgetarily feasible and technically feasible are jointly discussed**. In this way, **the knowledge and skills of the parties involved is used**. The result is a better perspective on the circular opportunities and associated costs. This leads to **opportunities for cost optimization and value addition** and thus promotes the chance of an optimal design to realize the ambitions set. In addition, one consultant stresses from experience that within these collaborations **safeguarding of (interim) results** remains important. If not, investors tend to deviate to cheaper less circular options.

Two consultants mention how these forms of **early-contractor involvement possibly also require different tendering methods**. In this regard, one consultant mentions **Rapid Circular Contracting (RCC)**. At RCC, the tender is awarded before the design phase to a group of experts. In the design phase, they devise an applied innovation or give substance to a circular challenge jointly. Besides, they also jointly formulate the ambitions.

5.3.5. *Online in-stock building material and components database and marketplace to foster matchmaking*

All consultants acknowledge that an **online marketplace to offer insights salvaged materials of to-be demolished building stock would be very helpful**. The sooner the insights, the sooner potential customers can find the salvaged materials. This is **very cost-efficient** because demolition contractors do not have to actively search for parties who want to purchase it. Working towards a database that provides insight into salvaged materials that are released during demolition projects is particularly necessary. In this way, demolition contractors can also **see what materials are**

released from demolition projects from other demolition contractors. Moreover, there could be an additional role for material brokers who actively try to link supply and demand to each other.

On top of that, another consultant argues that **arranging more in advance can also increase economies of scale**. For example, finding more buyers in advance can create harvesting salvaged materials from a residential area in larger quantities to create more economies of scale in further processing.

The architect also mentions that in case it is opaque what salvaged building materials will be released the **architect could be flexible in his design. For example, by describing only functionalities** in the specification drawing **and leaving final materials choices open**. This flexibility may limit the architect in the design, as it limits the number of specifics that can be included on the appearance of a building. However, it is opens up opportunities unanticipated future salvaged material release.

5.3.6. Elaborations on a business model for direct application of building materials in (local) construction projects

One consultant experienced **that circular projects are often more expensive, but not always**. Higher costs are incurred because reusing materials is more expensive than using its primary counterparts. The project often takes longer as well. Especially, if the collaboration form is new and everyone must get used to each other. Currently, from the cost perspective the **highest attainable achievement is that a circular project breaks-even**. **The practice of dismantling is more expensive, certainly if storage is required**. Even if the storage is 'free', there are always the indirect costs of keeping the storage location occupied (i.e. no rental profits). However, storage will remain important, even if immediate supply of salvaged materials is agreed upon. It can for example be the case that the construction project overruns, and storage is required.

5.3.7. Possible practical relevance of circular business ecosystem analysis prior to a circular project

One consultant argues that an **ecosystem analysis or scan prior to the project could help to translate the ambition "to do something with circularity" into possible ideas on what that means for the project in question.** It can help to jointly form a vision and objectives and define already certain roles, responsibilities, and commitments prior to the start. Also, it opens up thinking on how to reconcile personal interests with the objectives and how to overcome possible barriers.

Still, it should be tested how the ecosystem analysis can be best translated to practice. Like, how to **phrase** questions such that everyone understands the meaning. Besides, it would be helpful to explore which questions are most practically relevant and in which order they could be discussed best. In this regard, another consultant proposes to ask the questions about barriers (and how to overcome these) lastly. Barriers she has encountered in practice are for example persons (and hence knowledge) that leave the project or a local changing political arena.

In addition, the **questions probably should be tailored to each project individually**. Besides, when using such an ecosystem analysis prior to the project it is advisable to **not record too much in advance or set too rigid ambitions**, as there **should always be space for flexibility along the project**. New circular options can also arise during the project.

5.5. Contribution to academic literature

The first contribution of this study is the formulation of a definition of a circular business ecosystem based on academic literature. According to this study, a circular business ecosystem can be defined as '*a set of actors that work jointly towards achieving the collective outcome of slowing, narrowing, closing, or regenerating the loop on resources*'.

Second, no ecosystemic lens was yet applied to describe the ways on how high value reuse and recycling is achieved in the built environment. A comprehensive overview of all circular value chains and circular demolition (and) construction projects was the result of applying a circular business ecosystem lens to demolition contractors. Applying a circular business ecosystem perspective has provided insights in the actors and their roles needed, their mutual use of capabilities, their interdependencies and the physical and virtual infrastructure needed to actualize high value reuse and recycling. It also gathered insights in what kind of actor role and interaction pattern changes are required and what advantages ecosystem collaborations can bring.

Besides, this research also provided a detailed 6C-framework to study circular business ecosystems. Since a framework to analyze circular business ecosystems was lacking this is also considered a contribution to academic literature. Upon the findings of this research the questions to analyze circular business ecosystems are displayed in Figure 5. These questions can be used as a guidance to future circular business ecosystem research.

Furthermore, circular business model research could be extended by adding an additional layer of ecosystem overview to the standard (circular) business model canvas. Lüdeke-Freund (2019) found that insights in the networks and relational aspects of circular business models are nearly absent. An additional circular business ecosystem analysis can provide insights in the collaboration, capabilities, construct, and configuration surrounding the circular supply network.

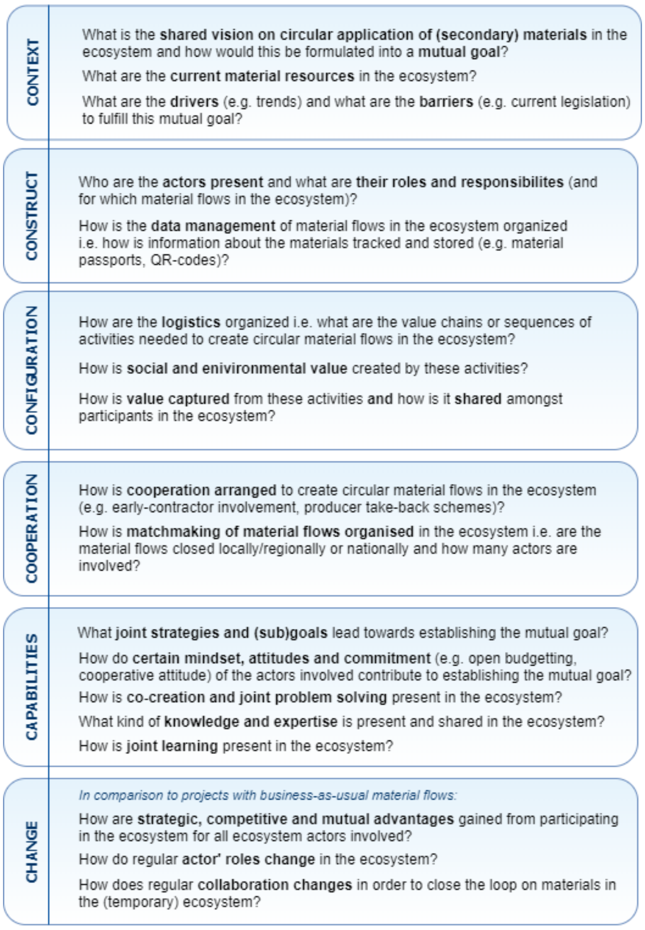


Figure 5. Questions for future research to provide a comprehensive overview of a circular business ecosystem

5.6. Practical relevance of the study

From the results follow that connecting old building material stock directly to future construction projects increases the possibility of high value applications. The **development of a (national) database where all future salvaged materials from the future demolition stock will be inventoried and registered** will be helpful in this regard. This database could operate with a **national ecosystem of demolition contractors** and requires search method to find building materials in a certain location to foster local or regional matchmaking. Making use of this database, architects and project developers can find future secondary building materials. This enhances future matchmaking to new construction projects that could even be facilitated by third parties, like independent material brokers that actively search for potential construction or renovation projects. In case matchmaking with (local) projects is not achieved, the salvaged materials could also be coupled to high value reuse and recycling routes. For matchmaking to new-build projects clients, like governmental parties should provide insight into future new renovation and construction projects of the Central Government Real Estate portfolio.

To results also show that establishing collaboration in the very beginning of a circular C&D project is regarded as fruitful. In practice, **governmental bodies and clients could actively steer towards these kinds of collaborations in the beginning of future construction projects**. Suitable collaboration forms are those that involve contractors in early stages (i.e. early-contractor involvement). These collaborations foster knowledge and experience exchange, joint problem solving and co-creation to realize ambitions. Examples of this early-contractor involvement collaboration forms are a construction team (in Dutch: bouwteam) or testing ground set-up (in Dutch: proeftuin). If matchmaking is not possible in the design stage, architects could leave material choices opened in their designs (i.e. by describing functionalities rather than material choices) creating space to exploit opportunities to use secondary materials in a later building phase. This will aid to move away from the common linear chain of processes in the building's life cycle that is without collaboration and is not particularly effective for circular material decision-making.

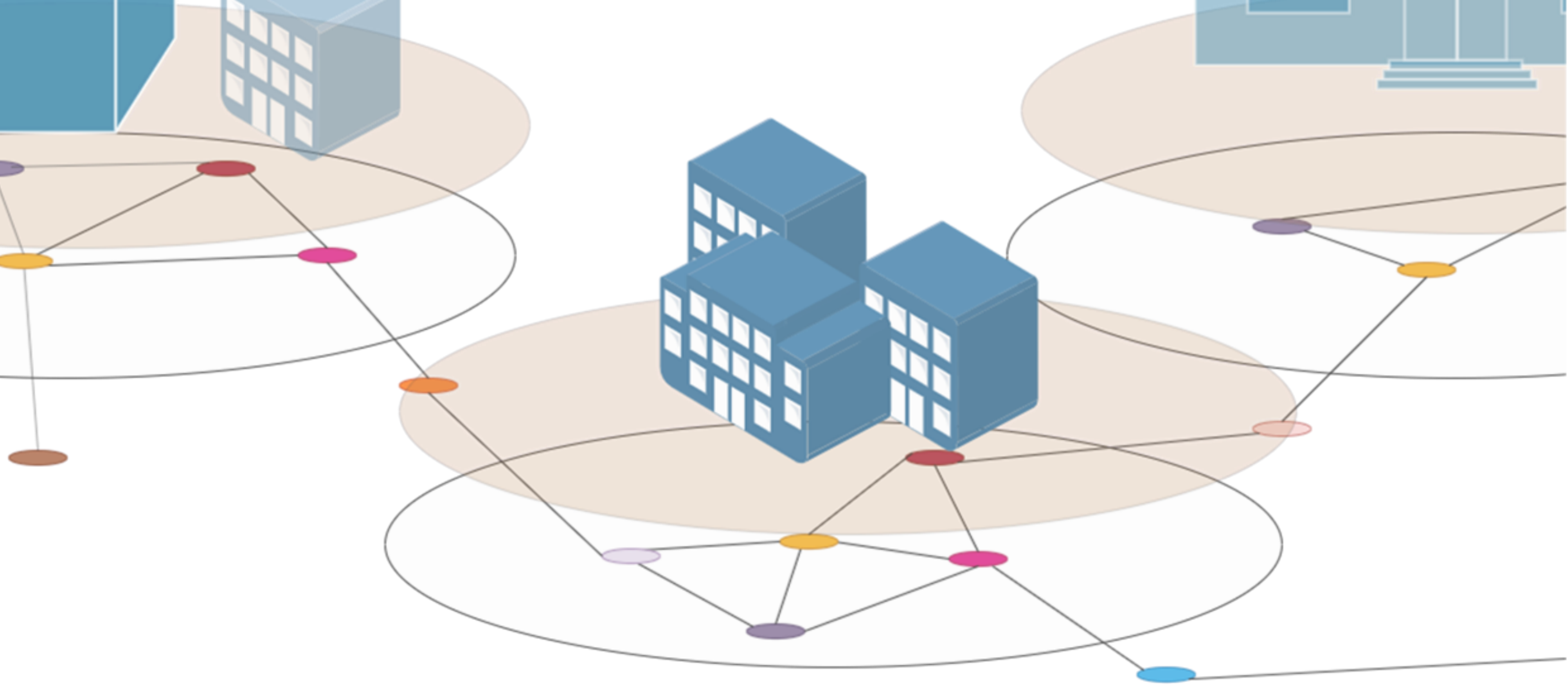
Lastly, from the results follow that local or regional hubs for refurbishment are helpful to establish high value reuse and recycling. Subsequently, **all C&D actors and the government should steer towards an increased set-up of hubs**. These can also operate as a **logistic center** that functions as transit point for refurbished materials to local building contractors. This entails collaborations or circular business ecosystem developments by local demolition contractors and building contractors. Additionally, physical marketplaces can be used for other useful salvaged materials that have no refurbishment route. This will probably concern supply to smaller building contractors, private individuals, and small companies to (re)build houses or home or small offices.

5.7. Last critical note

Using salvaged materials to create secondary building materials is part of the circular economy transition in the built environment. However, from a sustainability point of view, it is not only best to strive for long-lasting building products and components, but also for long-lasting buildings (e.g. > 300 years). Contradictory, long-lasting buildings hamper the circular business model of reuse, recycle, or refurbishment of salvaged building materials.

Besides, to create long-lasting building products and components one could think of providing these *as-a-service*. This was also mentioned by interviewee C. In this case the customer pays for the service provided by the company instead of owning the product (Tukker, 2015). Providing building components as-a-service can undermine the business model of the demolition contractors to orchestrate value chains for high value reuse and recycling themselves. In the case of as-a-service building components the producer remains the owner of the building materials or component and the demolition contractor will simply dismantle the material or components and return them.

Lastly, interviewee B mentioned the case of high value masonry recycling briefly during his interview pointing out the benefit of shorter drying time of bricks when powder was used from crushed old masonry bricks. However, in the regular Dutch masonry production river clay is used as a left-over product from dredging the river delta. According to the interviewee, this results in hardly any incentives to move towards circular masonry. This example intrigues to ask prior to any circular value chain orchestration whether it is sensible to invest in high value recycling, if already other left-over waste products are used in the production process.



6. Conclusions

Final research conclusions

6. **Conclusions**: final research conclusions

This section covers all sub research questions and answers, answer to the main question, outlook, research recommendations and limitations to study.

6.1. Answers to sub research questions

In conclusion to the sub research question*: What are the current barriers and enables to achieve high value reuse and recycling in the (Dutch) built environment?* The findings are as follows:

Regarding barriers to high value reuse and recycling, several barriers were mentioned by authors. First, the need to adapt and refine salvaged materials is accompanied with additional costs of retrieval and processing. This makes value reuse or recycling not always economically interesting. Second, in case of lacking information on material characteristics, additional material tests (and costs) are often required (Ghaffar et al., 2020). Third, there is often a mismatch between demand and supply of salvaged building materials and components, because the quality and quantity supplied can turn out to be insufficient (Ghaffar et al., 2020). Besides, intermediate storage and logistics can be hurdles to accomplish a solid business case as these increase (environmental) costs (Ghaffar et al., 2020). Lastly, salvaged materials may not meet obligatory building and quality requirements and energy standards, which hampers high value (direct) reuse (Kok & Koning, 2019).

In regard to enablers, several ideas were proposed by authors. Ruiz et al. (2020) advised improvements on C&D waste handling across the building' life cycle stages. These included the advice to execute on-site sorting activities and conducting pre-demolition audits to assess the potential to high value material reuse, recycling and reselling in advance to dismantling. Leising et al. (2018) stressed the importance of producer take-back schemes and marketplaces as part of achieving high value reuse and recycling. Furthermore, legislations, regulations and impact calculation tools can enhance high value reuse and recycling of salvaged materials. To stimulate circular practices, governmental policies, incentives and voluntary agreements are present in the Netherlands. This is in line with the ambition of the Dutch government to become fully circular by 2050.

In conclusion to the sub research question*: what is a circular business ecosystem and how can we analyze it?* the following are the main findings.

A circular business ecosystem can be defined as '*a set of actors that work jointly towards achieving the collective outcome of slowing, narrowing, closing, or regenerating the loop on resources*'. A circular business ecosystem can be analyzed by a 6C-dimensional framework describing context, construct, configuration, cooperation, capabilities, and change. The **Context** dimension can be best described as environmental features (i.e. characteristics of the environment) of the circular business ecosystem. The **Construct** dimension entails infrastructure and structure (i.e. constructive elements) of the circular business ecosystem. The **Configuration** describes all activities in the circular supply network and how these form configuration patterns. The **Cooperation** dimension describes all collaborations and governance mechanisms of the circular supply network. The **Capabilities** dimension entails the key success features (or capabilities) of the circular supply network. The **Change** dimension is the process of shifting from one business ecosystem configuration pattern to a (more) circular configuration pattern.

In conclusion to the sub research question*: how is high value reuse and recycling achieved following a demolition contractor perspective?* The following are the main findings:

There are several routes to high value reuse and recycling and configuration patterns present in the demolition sector. A total of eleven routes were retrieved from the data, of which six are concerned with organizing value chains and four involved project collaborations. Regarding value chains, these routes differ per component or material type. Value is created from applying free salvaged materials to the project or selling sorted/clean salvaged materials for refurbishment or recycling. Costs are mainly due to the labor costs for dismantling and reprocessing of materials. Subsidies could be used to cover cost risks and research trajectories. Depending on the route and transport distance, esthetic, environmental and social value is created. Circular value chains start with heterogenous and small group of actors, for example a (group of) demolition contractor(s), a (few) wholesaler(s) and a refurbishment party or; a demolition contractor and a recycling party or; a (group of) demolition contractor(s) and a (group of) building contractor(s). But the number of actors can increase to multiple demolition contractors (and building contractors) joining to create economies of scale and cost-efficiencies. All routes and all subsequent roles found in this research are found in Figure 6.

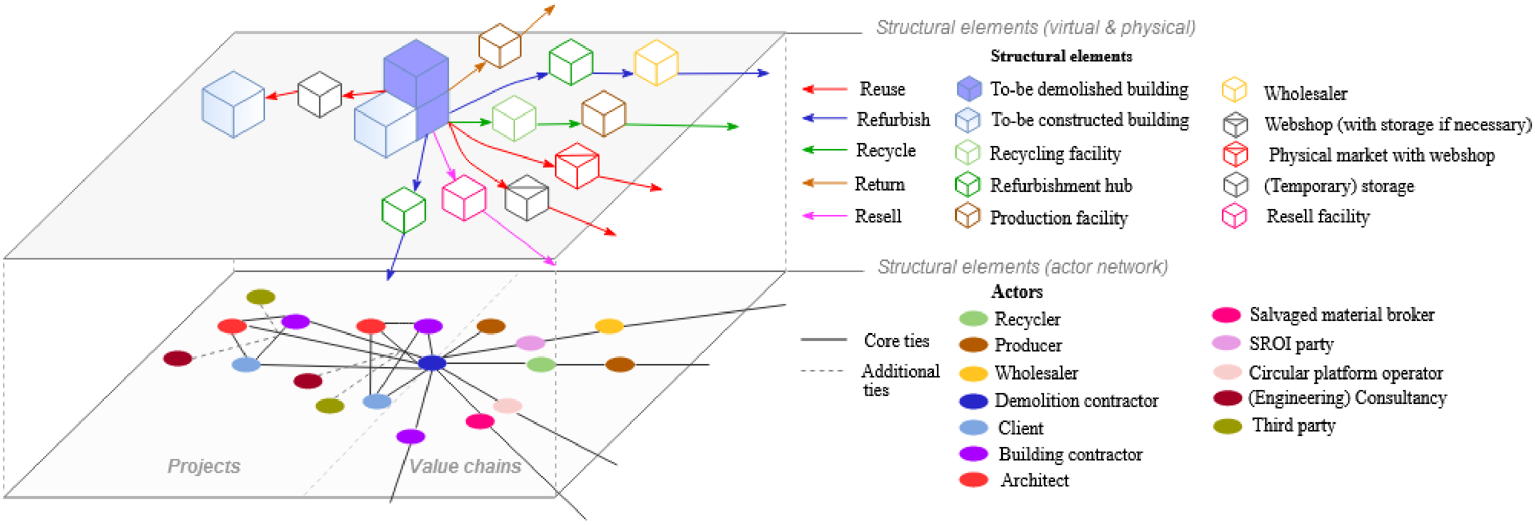


Figure 6. This figure shows the configuration patterns (upper layer) and actor construct (lower layer). It does not include internal recycling as this does not involve direct cooperation with other actors. Scholars and customers are not included as actor categories is not included as they are not bound to a configuration. Customers are not included as the circular products resulting from the value chains may well end-up at customers like (small) architects and builders, but also private individuals and even may return to the local new construction project. Therefore, the arrows and lines are flowing out to undefined actors and directions.

For product with take-back schemes, producers have a key role in providing take-back schemes for internal recycling and refurbishment programs. For recycling routes, recyclers play a key role to convert salvaged materials into new aggregates for production. For refurbishment routes, refurbishment hubs are operated by demolition contractors (and building contractors). Social enterprises can provide Social Invest on Return (SROI) working spaces or provide labor to accomplish the refurbishment tasks. From the demand-side, wholesalers are needed that want to retail the refurbished secondary building materials or components or building contractors as a logistic partner, directly taking the materials from the refurbishment hubs to construction works.

For reuse, salvaged materials and components are either offered at online marketplaces can be used before dismantling or on a physical marketplace after dismantling. In case of offering the materials in advance of dismantling, material inventory (by tablet) is required to register the material specifics and date and time of release of the building materials (e.g. by pictures, descriptions, and product codes).

On project level, a heterogeneous and small group of actors is needed to achieve high-quality reuse and recycling, collaborating at the start of the construction process. This group of actors should at least consist of the architect, demolition contractor, building contractor and client. Building material loops are preferably closed as local as possible on project level as this is most economic and environmental cost-efficient. All actors involved play an important role as they provided the expertise, knowledge and capabilities and partnerships needed. For achieving high value reuse and recycling ambitiously it is important that they jointly set goals and strive to jointly work towards achieving these. In this regard, it is important that the client values circularity as part of the project, provides the required time for proper pre-dismantling material inventory and considers matchmaking with own future construction or renovation projects.

In case of direct application to a construction or renovation project, architects create design from the available salvaged building materials and components. Building contractors make the required construction calculations and calculate the number the secondary materials needed for construction. Subsequently, they build with the salvaged or secondary materials and components. Demolition contractors inventory materials in the old building stock, selectively dismantle materials from the building stock, provide advice for design for deconstruction. If necessary, they can offer certain salvaged materials via their marketplace, resell parts to other traders in salvaged materials, pre-processing salvaged material to cleaner fractions for recycling, or search for direct use applications to other projects. Additionally, to track materials, QR-codes and material passports can be created. In addition, academia can provide research that supports circular business operations. Engineering and advisory companies can have a role in testing the qualities and characteristics of salvaged materials and in data management support. Subsequently, advisory companies can also help to find connections to other (local) construction or renovation projects. Independent parties can help to be a connecting factor in multi-actor construction team collaborations or testing ground set-ups. Herein, a spokesman for future tenants can also be present to represent and advocate the tenants' interests.

On project and value chain level knowledge, skills and experience sharing is regarded as important. In collaborations, actors should have an open, transparent, and flexible attitude. Trust in each other and each other's intentions, as well. All actors (and employees) need a mindset to work with circularity, jointly working towards the same goal, whilst being enthusiastic about circularity. In this regard, striving solely for own personal gains is not rewarded. There is atmosphere of joint learning and joint problem-solving present. Regarding, finding solutions to high value reuse and recycling of building materials some co-creation between actors may evolve. In any form of collaboration, open budgeting is preferred as it provides insights in costs that needs to be covered, creating grounded business case with fair returns for all actors.

Currently, exploring circular strategies to salvaged building materials in both orchestrating value chains and in projects follow a process of trial-and-error. For example, value chains require constant adaptation as these secondary products are trialed first (e.g. to gauge customer demand) and later optimized (e.g. by electrifying transport). To create economies of scale and sustain sufficient supply, hubs have a certain openness to other demolition contractors (and building contractors) to entry the hub logistics (e.g. collection points, refurbishment route). In this case there is a cooperative, rather than competitive attitude. For example, physical infrastructure can be shared amongst demolition contractors (and building contractors) in the form of hubs, but also as physical marketplaces

Process changes in value chains that are expected in C&D environment are for example an increased application of design-to-dismantle products, like demountable hollow slab floors and windowpanes. If concrete will be approximately 100% recycled this will also increase the number of high value recycling possible significant. Besides, the number of refurbishment hubs will increase when demolition contractors are ambitious in high value reuse of building components. In this regard, collaboration with building contractors create efficiencies. The virtual registering materials and subsequent local matchmaking activities, like uploading material passports and specifics of future demolition projects is expected to play a vast role in matchmaking old building stock to new construction projects. Additionally, demolition contractors will continue finding ways to deal with C&D waste in high value ways.

In the case of direct application of salvaged material in (local) circular construction projects, the workflow is changing from the linear project management flow to a variant where all relevant C&D actors (i.e. at least the architect, client, building and demolition contractor) are involved in the beginning of the project. Demolition contractors will have an advisory role that involves inventory and dismantling of salvaged materials and components. Besides, they can offer possibilities for (high value) reuse and recycling. There are certain advantages for demolition contractors to engage in circular projects and to orchestrate circular value chains. For example, they attract clients that are affiliated with circularity. Besides, when tenders will be awarded on quality criteria like circularity, they can offer different routes to high value reuse and recycling and expertise on circularity.

6.2. Answer to main research question

In final answer to the main research question*: How can high value reuse and recycling of building materials and components be achieved in the Dutch C&D environment, following a circular business ecosystem perspective?* is threefold:

First, **high value direct application and processing of salvaged materials is most preferable achieved locally.** Both from an environmental and cost perspective. Second, achieving this involves **early-contractor collaboration in circular projects** (e.g. of construction and demolition contractors, architects and clients in the design phase) to discuss the technical and financial feasibility of applying salvaged materials from old to new constructions. In these collaborations and open, transparent and cooperative attitude is required. This can be fostered by open budgeting. Last, achieving (local) **high value direct application of salvaged materials requires matchmaking, preferable before dismantling**. If no early matchmaking takes place, architects can create flexible designs with respect to material choice, leaving space to exploit future opportunities of salvaged material release. Besides, there are **options to further handle and process salvaged materials in (local) circular value chains**.

Elaborations on this conclusion are described in the following subsections.

6.2.1. Local handling and processing of salvaged materials is most preferable

Several high value circular strategies for building materials and components were found in this inquiry. These are all displayed in Figure 7a. From the results followed that high value reuse and recycling achievements are most cost and environmental efficient when the loop is closed locally. Hence, local reuse and reprocess of building materials is preferred. Accordingly, circular strategies to achieve high value handling of salvaged building materials can be subdivided geographically. These strategies can be distinguished into *on-site*, *close-by* site (i.e. local) and *away from* site (i.e. non-local). Figure 7a displays six connected circles. The left circles contain high value circular processing options for end-of-use salvaged building materials in a circular demolition projects. The right circles contain these for circular construction projects. These cycles are interconnected because they cannot exist without each other. Clients, architects and building contractors (driven by high circularity ambitions) need to apply salvaged and secondary building materials to construction or renovation projects, otherwise building material loops cannot be closed. There is a dependence of demand of secondary materials and supply from old building materials. For direct application, the first step is to explore what opportunities are present *on-site* to transform the building, leaving certain parts of the building in-tact. Subsequently, the opportunities for high value reuse and recycling of the salvaged building materials can be explored *close-by* and *away from the location*. For example, reusing part of the structure in a *close-by* (a local) new construction project(s) can be discussed. Also, one can explore together with the (future) client (e.g. housing corporation or government) if any salvaged materials from the demolition project can be used in (*close-by*) future construction or renovation projects of the client.

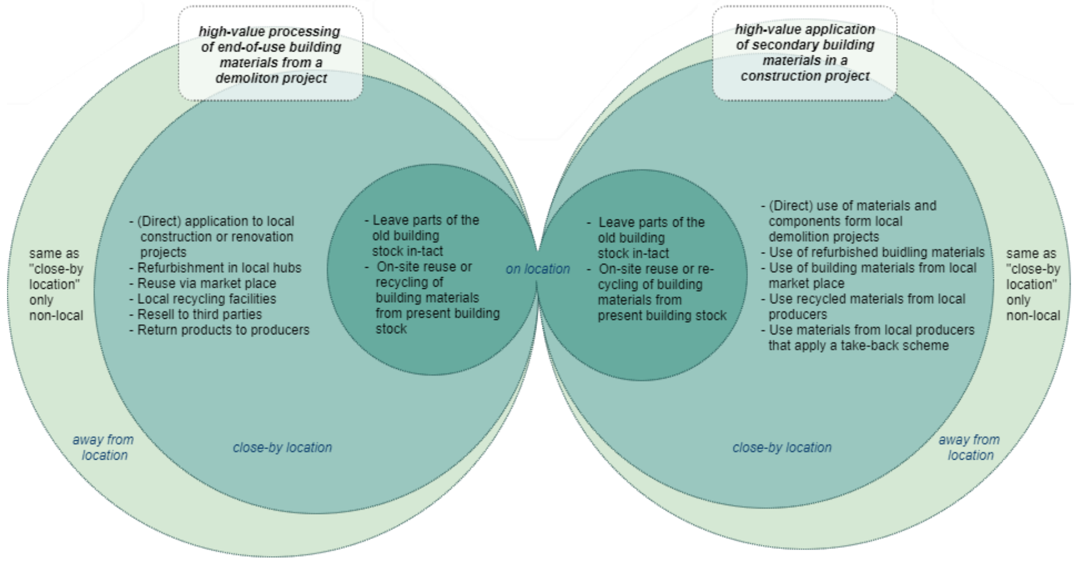


Figure 7a. High value application of building materials from the demolition perspective and its subsequent actions needed from the construction perspective. The inner circle reflects applied circular strategies on-site, the middle circle reflects the application of circular strategies close-by the site and the outer circle reflect all circular strategies applied non-locally, further away from the site. Internal recycling of building material for own business operations is excluded in the picture, as this is not quite regarded as high value reuse (as it is not used as building material, but for other (lower-value) purposes).

Figure 7b displays a hypothetical example of a circular construction project to create an office building out of a student flat on-site. In this case, the client has chosen to establish an early-contractor collaboration between the client, architect, demolition and building contractor to accomplish the project. They have chosen several high value reuse and recycling strategies for *on location*, *close-by site* and *away-from site*. *On location*, the team has chosen to leave the steel structure in-tact, reuse the indoor doors, and use on-site concrete recycling. *Close-by site*, they have chosen to use refurbished suspended ceilings and refurbished wooden beams from hubs. They also used lighting from another local demolition project. They could not use several salvaged materials from the old building stock in the new construction project, so these were displaced to a local marketplace and renovation project *close-by site*. The gypsum plates that were retrieved from the old-building stock did not have the right measurements and hence, were recycled *away from the location*. This delivery was coupled to the purchase of new recycled secondary gypsum plates with proper measurements of the same factory. Remanufactured carpet tiles were used that have a take-back scheme.

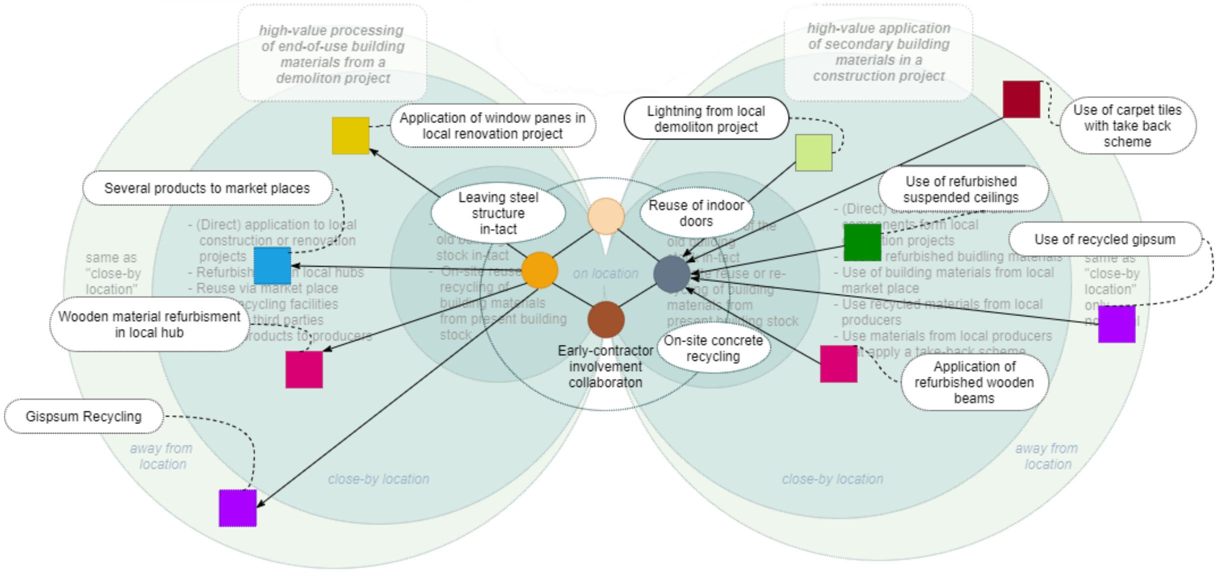


Figure 7b. All dots are actors. Brown is architect, pink is client, grey is building contractor and orange is demolition contractor. All blocks are entities where circular processing of materials takes place. The strategies to high value processing of salvaged building materials are displayed left, and high value application of secondary building materials on the right. The inner circle reflects applied circular strategies on-site, the middle circle reflects the application of circular strategies close-by the site and the outer circle reflect all circular strategies applied non-locally, further away from the site. The blocks represent the locations of the reuse, recycle, refurbish or resell routes. If the block has the same color, they correspond to the same route.

6.2.2. Circularity of buildings materials is currently only achieved in collaboration between C&D actors

Because of the nature of the built environment in which every project is different, it is arguable to describe circular C&D projects as temporary circular business ecosystems. Here, a set of C&D actors jointly work towards achieving the collective outcome of closing the loop on building materials and components on a project scale. From the study followed that when connecting a local demolition project to a local constructing project early-contactor collaborations are mainly suitable to the challenge of high value reuse and recycling. These kind of collaborations opens opportunities actively use the capabilities and knowledge to achieve high value application of materials from the old building stock in new construction projects. In all collaborations an open, transparent and cooperative attitude is required.

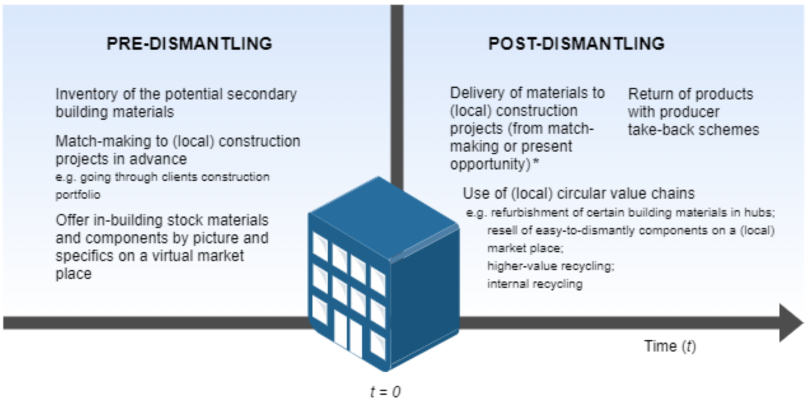
For non-direct application, there is a dependency on the value chains orchestrated to establish high value reuse or recycling of salvaged building materials. Some demolition contractors offer high value refurbishment or recycling possibilities of certain materials and components, others offer reuse possibilities via their own marketplaces. Besides, some producers of building components (e.g. carpet tiles, lightning, and elevators) work with take-back schemes. These circular value chains can be regarded as enduring circular business ecosystems. For example, refurbishment chains are operated by multiple demolition contractors, building contractors and wholesalers. Here, C&D actors also jointly work towards achieving the collective outcome closing the loop on building materials and components for a lasting period. Together they can use each other's knowledge and infrastructure to enhance circularity in the built environment. They work towards a shared future in which circular building materials will play an increasingly important role.

6.2.3. Pre- and post dismantling activities needed to succeed high value circular strategies

Prior to dismantling, it is needed to inventory the building materials in the to-be demolished building stock and search for possible matchmaking with (a couple of) local construction and/or project(s). This involves conducting pre-demolition audits to explore what materials are present in the building. Accordingly, the salvaged materials and components specifics can be uploaded (e.g. in the form of material passports or photographs) on an online (marketplace) platform (without or only minor storage) in the pre-demolition stage. Architects and project developers can subsequently inventory and make bids on the salvaged materials that will become available. Material brokers can actively reach out these parties to connect the future outflux of materials to construction projects. When matchmaking is accomplished these parties can sit together to explore all possibilities for the construction project or start early-contractor collaborations. In case, matchmaking is not accomplished, the architect can decide to describe functionalities in the specification drawing with flexibility on material choice. This leaves space to exploit future opportunities of unanticipated salvaged materials release in pre-demolition phase of other buildings.

After dismantling, the salvaged materials and components can directly be applied to local construction and/or renovation project(s) in case of successful pre-dismantling matchmaking. If due to any (unforeseen) circumstances, they cannot be directly applied to the construction project, they need some intermediate storage. Products with take-back schemes are delivered back to the producers. The rest of the salvaged materials can be processed in (local) circular value chains. For example, via online marketplace with storage, via hubs that conduct refurbishment activities, or via recyclers.

Figure 8 summarizes the pre- and post dismantling activities needed to achieve high value reuse and recycling of salvaged building materials and components, in one picture.



* this can possibly be with intermediate storage

Figure 8. This figure shows what activities are needed if t < 0 or t > 0, when at t = 0 dismantling operations are carried out. If t < 0 finding potential clients is key to high value applications to salvaged materials. This can for example be achieved by matchmaking with another or other construction and renovation projects. Post-dismantling salvaged materials are delivered to clients from previous matchmaking or from current matchmaking, products with take-back schemes are returned to the manufacturer and the rest of the materials finds it way to (local) circular value chains.

6.3. Limitations to study

There are several limitations to this study. First, all demolition contractors were interviewed on their circular services and products offered, resulting in an overview of several value chains and projects. However, as followed from the final conclusions, these could actually be perceived as ecosystem collaborations on their own. In this regard, the focus of analysis was too broad to provide all specifics on the ecosystems found. The results are more general descriptions of the 6C-dimensions that included information on both circular value chains as circular project collaborations.

Second, the interview protocol and code scheme used, were based on the findings on circular (business) ecosystem literature and the 6C-framework of Rong et al. (2015). First, the 6C-dimensions of Rong et al. (2015) were to a certain extent interpreted upon the author's interpretation of what the categories entailed. Subsequently, the 6C-dimensions and the code scheme were translated and detailed to a circular business ecosystem perspective. This process was influenced by the author's significant expertise in the field of circularity, but minor expertise on business ecosystems prior to the start of this research. Resultingly, if the framework tailoring would be repeated by an expert in the field of business ecosystem research this may result in a slightly different framework. Besides, detailing was achieved upon only 11 articles, as there was not much literature available yet on circular (business) ecosystems. Hence, the tailored explanatory subcategories of the 6C-dimensions possibly need adaptation when new insights arise when the research field expands. Therefore, the process of subcategory explanation should be further updated and refined by other researchers to the latest insights in the field of circular business ecosystems.

Lastly, the results section originated mainly from 4 interviews with little secondary data. This has the drawback that the findings are hard to generalize. The session with practitioners helped to verify the findings. However, the main findings and generalizations may overlook circular value chains or important information on how circular C&D projects thrive.

6.4. Research outlook

In this research a firm-centric angle was used by focusing on demolition contractors as initiators of circular business ecosystems. This analysis was focused on how (a person within) a company orchestrates the ecosystem to close the loop on materials. This was found suitable to demolition contractors, as they provide multiple routes to certain materials and components. However, as previously mentioned, the scope of the research turned out to be broad, since the demolition contractors orchestrated many circular value chains and were part of several circular C&D projects. Hence, to get a more specific overview of an ecosystem it is rather recommended to conduct circular business ecosystem research from a product/service/project/initiative-centric perspective. In this regard, also other C&D actors like building material producers that produce *a certain* product or clients that aim to realize *a certain* circular C&D project can become the focus of analysis. Regarding the latter, one could conduct a cross-comparison case study analysis on how temporary circular ecosystems are orchestrated around several circular C&D projects. This will partly verify or challenge the more generalist findings of this research as well.

It is further recommended to broaden the descriptive analyses of 6C-dimensions in the circular business ecosystem framework with more established tools in academic research. For example, by adding Stakeholder Analysis to the Construct dimension and Material Flow Analysis to determine the material flows in the ecosystem in the Configuration dimension.

6.5. Further research recommendations

Lastly, from the findings followed that early-contractor involvement is a promising form of collaboration in circular C&D projects. Osaily et al. (2019) found that early-contractor involvement of demolition contractors in projects fosters reasonable circular decision-making on salvaged materials and design for deconstruction in the early stages of the design process. This may result for example in an early consideration of the end-of-life phase in the design phase by adding a planning and risk assessment for the deconstruction process (Osaily et al., 2019). According to Osaily et al. (2019) the advantages of early involving demolition contractors in the design phase, outweigh the perceived barriers of extra cost and time and possible clashes incurred in these collaborations. Further research can involve a cross-comparison case study analysis on cases in the Netherlands to determine the key success factors in such collaborations.

References

Adams, K. T., Osmani, M., Thorpe, T., & Thornback, J. (2017, February). Circular economy in construction: current awareness, challenges and enablers. In *Proceedings of the Institution of Civil Engineers-Waste and Resource Management* (Vol. 170, No. 1, pp. 15-24). Thomas Telford Ltd.

Adams, W. C., & Newcomer, K. E. (2015). Conducting semi-structured interviews. In Handbook of practical program evaluation (4^{th} edition). (pp. 492–505). Hoboken, NJ, USA: John Wiley & Sons, Inc.

Albers, Luijten & Van Dinther (04-06-2019). Op weg naar circulair slopen. Retrieved from: https://www.cirkelstad.nl/op-weg-naar-circulair-slopen/

Alexandris, G., Katos, V., Alexaki, S., & Hatzivasilis, G. (2018, September). Blockchains as enablers for auditing cooperative circular economy networks. In 2018 IEEE 23rd International Workshop on Computer Aided Modeling and Design of Communication Links and Networks (CAMAD) (pp. 1-7). IEEE

Antikainen, M., & Valkokari, K. (2016). A framework for sustainable circular business model innovation. *Technology Innovation Management Review*, 6(7).

Arnold, M. (2017). Fostering sustainability by linking co-creation and relationship management concepts. *Journal of Cleaner Production*, *140*, 179-188.

Betonakkoord (2018). Het Betonakkoord. Retrieved from: https://www.betonakkoord.nl/betonakkoord/

Brand, S. (1995). *How buildings learn: What happens after they're built*. Penguin.

CBS (December, 2019). Bouw- en sloopafval: vrijkomen en verwerking, 1985-2016. Retrieved from: HYPERLINK "http://www.clo.nl/nl014711" ww.clo.nl/nl014711

CCentobelli, P., Cerchione, R., Chiaroni, D., Del Vecchio, P., & Urbinati, A. (2020). Designing business models in circular economy: A systematic literature review and research agenda. *Business Strategy and the Environment*, *29*(4), 1734-1749.

Cramer, J. M. (2020). Practice-based model for implementing circular economy: The case of the Amsterdam Metropolitan Area. *Journal of Cleaner Production*, 120255.

Creswell, J. W. (2009). *Research design : qualitative, quantitative, and mixed methods approaches* (3rd ed.). Sage.

Debacker, W., Manshoven, S., Peters, M., Ribeiro, A., & De Weerdt, Y. (2017). Circular economy and design for change within the built environment: preparing the transition. In *International HISER Conference on Advances in Recycling and Management of Construction and Demolition Waste*.

Eisenhardt, K.M., 1989. Building theories from case study research. Acad. Manag. Rev. 14, 532–550.

Frosch, R. A., & Gallopoulos, N. E. (1989). Strategies for manufacturing. *Scientific American*, *261*(3), 144-153.

Geisendorf, S., & Pietrulla, F. (2018). The circular economy and circular economic concepts—a literature analysis and redefinition. *Thunderbird International Business Review*, 60(5), 771-782.

Geissdoerfer, M., Savaget, P., Bocken, N. M., & Hultink, E. J. (2017). The Circular Economy–A new sustainability paradigm?. *Journal of cleaner production*, 143, 757-768.

Ghaffar, S. H., Burman, M., & Braimah, N. (2020). Pathways to circular construction: An integrated management of construction and demolition waste for resource recovery. *Journal of Cleaner Production*, 244, 118710.

Ghisellini, P., Cialani, C., Ulgiati, S. (2016). A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems. *Journal of Cleaner Production*, 114, 11–32

Ghisellini, P., Ripa, M., Ulgiati, S., 2018. Exploring environmental and economic costs and benefits of a circular economy approach to the construction and demolition sector. A literature review. *Journal of Cleaner Production*, 178, 618-643.

Gorgolewski, M., Straka, V., Edmonds, J., & Sergio-Dzoutzidis, C. (2008). Designing buildings using reclaimed steel components. Journal of green building, 3(3), 97-107.

Gupta, S., Chen, H., Hazen, B. T., Kaur, S., & Gonzalez, E. D. S. (2019). Circular economy and big data analytics: A stakeholder perspective. *Technological Forecasting and Social Change*, *144*, 466-474.

Hsieh, Y. C., Lin, K. Y., Lu, C., & Rong, K. (2017). Governing a sustainable business ecosystem in Taiwan's circular economy: The story of spring pool glass. *Sustainability*, 9(6), 1068.

Kok & Koning (September, 2019). EIB (Economisch Instituut voor de Bouw). Toekomstperspectieven Sloopsector 2019, Ontwikkeling en Vooruitzichten. Retrieved from: https://www.eib.nl/publicaties/gespecialiseerde-bedrijven/toekomstperspectieven-Kok & Koning-2019/

Konietzko, J., Bocken, N., & Hultink, E. J. (2020a). Circular ecosystem innovation: An initial set of principles. *Journal of Cleaner Production*, *253*, 119942.

Konietzko, J., Bocken, N., & Hultink, E. J. (2020b). A Tool to Analyze, Ideate and Develop Circular Innovation Ecosystems. *Sustainability*, *12*(1), 417.

Lacy, P., Long, J., & Spindler, W. (2020). Ecosystem. In *The Circular Economy Handbook* (pp. 283-300). Palgrave Macmillan, London.

Leising, E., Quist, J., & Bocken, N. (2018). Circular Economy in the building sector: Three cases and a collaboration tool. *Journal of Cleaner production*, *176*, 976-989.

Lemmens, C., & Luebkeman, C. (2016) *The Circular Economy in the Built Environment*. Retrieved from: https://www.arup.com/-/media/arup/files/publications/c/arup_circulareconomy_builtenvironment.pdf

Lüdeke-Freund, F., Gold, S., & Bocken, N. M. (2019). A review and typology of circular economy business model patterns. *Journal of Industrial Ecology*, 23(1), 36-61.

Mahpour, A. (2018). Prioritizing barriers to adopt circular economy in construction and demolition waste management. *Resources, Conservation and Recycling*, *134*, 216-227.

Migliore, M., Talamo, C., & Paganin, G. (2020). *Strategies for Circular Economy and Cross-sectoral Exchanges for Sustainable Building Products*. Springer International Publishing.

Moore, J. F. (1993). Predators and prey: a new ecology of competition. *Harvard business review*, 71(3), 75-86.

Moore, J.F. (1996). *The Death of Competition: Leadership and Strategy in the Age of Business Ecosystems*. HarperCollins Publishers.

Morse, J. M. (1991). Approaches to qualitative-quantitative methodological triangulation. *Nursing research*, *40*(2), 120-123.

Osaily, Y., Copping, A., McCann, S., & Uddin, T. (2019, September). Exploring the value of demolition contractor involvement at the design stage of construction. In *35th Annual Conference on Association of Researchers in Construction Management, ARCOM 2019* (pp. 334-343). Association of Researchers in Construction Management (ARCOM).

Parida, V., & Wincent, J. (2019). Why and how to compete through sustainability: a review and outline of trends influencing firm and network-level transformation. *International Entrepreneurship and Management Journal*, *15*(1), 1-19.

Parida, V., Burström, T., Visnjic, I., & Wincent, J. (2019). Orchestrating industrial ecosystem in circular economy: A two-stage transformation model for large manufacturing companies. *Journal of Business Research*, *101*, 715-725.

Potting, J., Hekkert, M., Worrell, E. & Hanemaaijer, A. (2017). Circular Economy: Measuring innovation in product chains. PBL Netherlands, Environmental Assessment Agency, The Hague. Retrieved from: https://www.pbl.nl/sites/default/files/downloads/pbl-2016-circular-economy-measuring-innovation-in-product-chains-2544.pdf

Rijksoverheid (September, 2016). Nederland circulair in 2050 - Rijksbreed programma Circulaire Economie. Retrieved from: https://www.rijksoverheid.nl/onderwerpen/circulaire-economie/documenten/rapporten/2016/09/14/bijlage-1-nederland-circulair-in-2050

Rijksoverheid (Februari, 2019). Uitvoeringsprogramma Circulaire Economie 2019 - 2023. Retrieved from: https://www.rijksoverheid.nl/documenten/rapporten/2019/02/08/uitvoeringsprogramma-2019-2023

Rong, K., Hu, G., Lin, Y., Shi, Y., & Guo, L. (2015). Understanding business ecosystem using a 6C-framework in Internet-of-Things-based sectors. *International Journal of Production Economics*, 159, 41-55.

Ruiz, L. A. L., Ramón, X. R., & Domingo, S. G. (2019). The circular economy in the construction and demolition waste sector–a review and an integrative model approach. *Journal of Cleaner Production*, 119238.

Saldaña, J. (2013). *The coding manual for qualitative researchers*. Sage.

Schraven, D., Bukvić, U., Di Maio, F., & Hertogh, M. (2019). Circular transition: Changes and responsibilities in the Dutch stony material supply chain. *Resources, Conservation and Recycling*, *150*, 104359.

Stake, R. E. (1995). *The art of case study research*. Sage

Tate, W. L., Bals, L., Bals, C., & Foerstl, K. (2019). Seeing the forest and not the trees: Learning from nature's circular economy. *Resources, Conservation and Recycling*, 149, 115-129.

Tukker, A. (2015). Product services for a resource-efficient and circular economy–a review. *Journal of cleaner production*, *97*, 76-91.

Vandecasteele, C., Heynen, J., Goumans, H., 2013. Materials recycling in construction: a review of the last 2 decades illustrated by the WASCON conferences. Waste and Biomass Valorization 4, 695e701. https://doi.org/10.1007/s12649- 013-9239-6.

Wang, Y., Han, J. H., & Beynon-Davies, P. (2019). Understanding blockchain technology for future supply chains: a systematic literature review and research agenda. *Supply Chain Management: An International Journal*.

Yin, R. K. (2009). Case study research: Design and methods. Sage publications. *Thousand oaks*.

Yuan, H. (2017). Barriers and countermeasures for managing construction and demolition waste: A case of Shenzhen in China. *Journal of Cleaner Production*, 157, 84-93.

Zucchella, A. (2019a). Value Propositions and Business Models for Circular Entrepreneurship. In *Circular Entrepreneurship* (pp. 61-88). Palgrave Macmillan, Cham.

Zucchella, A. (2019b). The Growth of Circular Entrepreneurship: An Integrative Model. In *Circular Entrepreneurship* (pp. 177-212). Palgrave Macmillan, Cham.

Appendix

Appendix A1. Additional background information to circular strategies in the built environment

The circular economy's principles

Potting et al. (2017) summarized circular economy strategies to enhance circular design and waste handling. In each product life cycle stage, there are different circular economy strategies. Potting et al. (2017) summarized them in order of preference from a waste minimization perspective. At the design stage of the product, one should aim for improving product design and manufacturing by using the circular economy strategies: refuse, rethink, reduce material use. To prolong the product's or product's components' lifetime one can use reuse, repair, refurbish, remanufacture, repurpose strategies. Repurpose is the use of discarded products (parts) in other products with different functionalities. Lastly, for end-of-life material recovery one can use recycling and energy recovery by incineration (Potting et al., 2017).

Table 1. 9R' circular strategies to maintain material value, figure adapted from Potting et al. (2017)

Product life cycle stage	Circular strategy
Optimization of material use in product design and manufacturing process	Refuse
	Rethink
	Reduce
Prolonging the product's (or product components') lifetime	Reuse
	Repair
	Refurbish
	Remanufacture
	Repurpose
End-of-life material recovery	Recycle
	Energy recovery by incineration

Circular economy & the built environment

Following the Shearing Layers of Change model from Stewart Brand's: how buildings learn, a building can perceived as composed of different layers with different lifetimes: site, structure, skin, services, space plan and stuff (see Figure 1). These layers are changed over the building's lifespan (e.g. during maintenance or renovation) (Migliore et al., 2020, p.86). Buildings can therefore be regarded as '*complex entities composed of many different long-life components*' (Migliore et al., 2020, p.86). Accordingly at demolition, demolition contractors deal with all the product, components and materials in these layers.

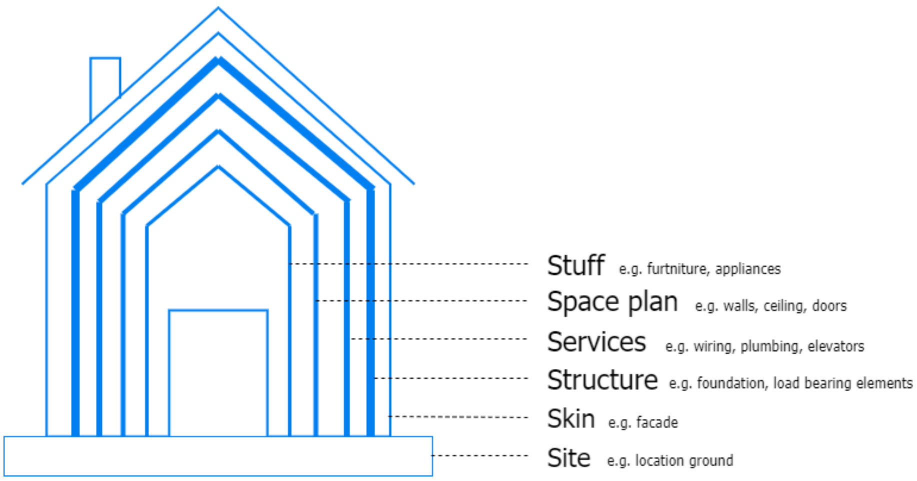


Figure 1. Shearing Layers Model from the book of Stewart Brand (1995): *how buildings learn* . Products, components and materials in each layer have different expected functional lifetimes.

The built environment and the circular economy

The adoption of circular economy principles over the entire building's lifecycle. It requires for example, a change in building design, choice of building materials and C&D waste handling. In the design stage, circular building design strategies to prevent future building material disposal and enable the use of secondary building materials are applied (Adams et al., 2017). Examples are: Design for Waste Prevention (i.e. using proper building materials and components with end-of-life in mind), Designed for Dismantling and Deconstruction (DfD), Design from Waste and Design for Adaptability and Flexibility (Adams et al., 2017). In the end-of-life stage, circular strategies can be applied like deconstruction, selective demolition, material and component reuse and closed-loop recycling (Adams et al., 2017). All these strategies over the are displayed in Table 2.

Table 2. CE strategies across a building's life cycle (Adams et al., 2017)

Design	Manufacturing & Supply	Construction	In-use and refurbishment	End-of-Life
- Design for Disassembly - Design for Adaptability and Flexibility - Design from waste - Modular by Design - Specification of reclaimed materials - Specification of recycled materials	- Eco-design principles -Reducing/optimizing material use - Reducing hazardous material use - Extended lifecycle - Design for product disassembly - Design for product standardization - Secondary material use - Take-back schemes - Reverse logistics	- Waste minimization - Procurement of reused materials - Procurement of recycled materials - Off-site construction	- Waste minimization - Maintenance minimization - Simple upgrade and repair - Adaptability - Flexibility	- Deconstruction - Selective demolition - Product and component reuse - Closed-loop recycling - Recycling for closing the loop
All stages: information management (e.g. datasets and metrics)				

Appendix A2. Literature Selection of Literature Study Circular Business Ecosystems

To retrieve information, certain keywords were used. The keywords that were used in Google Scholar generated the results displayed in Table 9. The results were further screened on their scientific value. If they were not part of academic literature and they did not involve a connection between circularity and business ecosystems they were not regarded as relevant literature. The Google Scholar Database was used on 21-2-2020.

Table 9. Keywords used and results retrieved in Google Scholar Database (21-2-2020)

Keywords	Results	
"circular economy business ecosystem"	6, 1 met criteria, but was not found relevant	Only the article of Türkeli et al. (2019) met the criteria but the paper was not found relevant for this research since it took a notably different angle of research and was specifically centered around business ecosystems of independent mobile phone repair shop. In addition, the article did not mention a circular economy business ecosystem nor described one.
"circular business ecosystem"	21 initial, 1 met criteria	Vehmas et al. (2018) wrote about consumers attitudes and circular fashion and referred to the report when referring to a circular business ecosystem. Niinmaki & Karell wrote about closing the loop in fashion industries and also refer to circular business ecosystem. Most research found were reports on circular economy in relation to fashion. Hence, only the article of Tate et al. (2019) about learning from nature's circular economy was found relevant.
"circular ecosystem"	97 initial, 9 met criteria	Non relevant articles were related to tourism or chemistry used the ecosystem concept in way that was related to business literature. In total, 6 new articles were found relevant and 3 book chapters. Of these 2 articles were found not relevant and one was previously found at "circular business ecosystem" search term: Tate et al. (2019).

After a first readthrough especially the papers of Konietzko et al. (2020a) and Tate et al. (2019) revealed valuable insights on circularity in relation to the concept of a business ecosystem. Both developed principles that can be a used to describe certain elements of a circular business ecosystem. Another key article of Parida et al. (2019) was found from snowballing from the article of Konietzko et al. (2020b). This article was particularly helpful to explaining a circular business ecosystem. Parida et al. (2019) only focused on business ecosystems in manufacturing companies that produce a circular product or service. The rest of the literature in Table 9 was found supportive to some of the 6C elements. Furthermore, the literature review provided the information to articulate what a circular business ecosystem is.

Appendix A3. List of literature found on circular (business) ecosystems

Keywords: **"circular economy business ecosystem"**

Türkeli, S., Huang, B., Stasik, A., & Kemp, R. (2019). Circular Economy as a Global Business Activity: Mobile Phone Repair in the Netherlands, Poland and China. *Energies*, *12*(3), 498.

Keywords: **"circular business ecosystem"**

Vehmas, K., Raudaskoski, A., Heikkilä, P., Harlin, A., & Mensonen, A. (2018). Consumer attitudes and communication in circular fashion. *Journal of Fashion Marketing and Management: An International Journal*.

Niinimäki, K., & Karell, E. (2020). Closing the Loop: Intentional Fashion Design Defined by Recycling Technologies. In *Technology-Driven Sustainability* (pp. 7-25). Palgrave Macmillan, Cham.

Hvass, K. K., & Pedersen, E. R. G. (2019). Toward circular economy of fashion. *Journal of Fashion Marketing and Management: An International Journal*.

Tate, W. L., Bals, L., Bals, C., & Foerstl, K. (2019). Seeing the forest and not the trees: Learning from nature's circular economy. *Resources, Conservation and Recycling*, *149*, 115-129.

Keywords: **"circular ecosystem"**

Alexandris, G., Katos, V., Alexaki, S., & Hatzivasilis, G. (2018, September). Blockchains as enablers for auditing cooperative circular economy networks. In *2018 IEEE 23rd International Workshop on Computer Aided Modeling and Design of Communication Links and Networks (CAMAD)* (pp. 1-7). IEEE.

Cramer, J. M. (2020). Practice-based model for implementing circular economy: The case of the Amsterdam Metropolitan Area. *Journal of Cleaner Production*, 120255.

Gupta, S., Chen, H., Hazen, B. T., Kaur, S., & Gonzalez, E. D. S. (2019). Circular economy and big data analytics: A stakeholder perspective. *Technological Forecasting and Social Change*, *144*, 466-474.

Lacy, P., Long, J., & Spindler, W. (2020). Ecosystem. In *The Circular Economy Handbook* (pp. 283-300). Palgrave Macmillan, London.

Zucchella, A. (2019a). Value Propositions and Business Models for Circular Entrepreneurship. In *Circular Entrepreneurship* (pp. 61-88). Palgrave Macmillan, Cham.

Zucchella, A. (2019b). The Growth of Circular Entrepreneurship: An Integrative Model. In *Circular Entrepreneurship* (pp. 177-212). Palgrave Macmillan, Cham.

Konietzko, J., Bocken, N., & Hultink, E. J. (2020). Circular ecosystem innovation: An initial set of principles. *Journal of Cleaner Production*, *253*, 119942.

Konietzko, J., Bocken, N., & Hultink, E. J. (2020). A Tool to Analyze, Ideate and Develop Circular Innovation Ecosystems. *Sustainability*, *12*(1), 417.

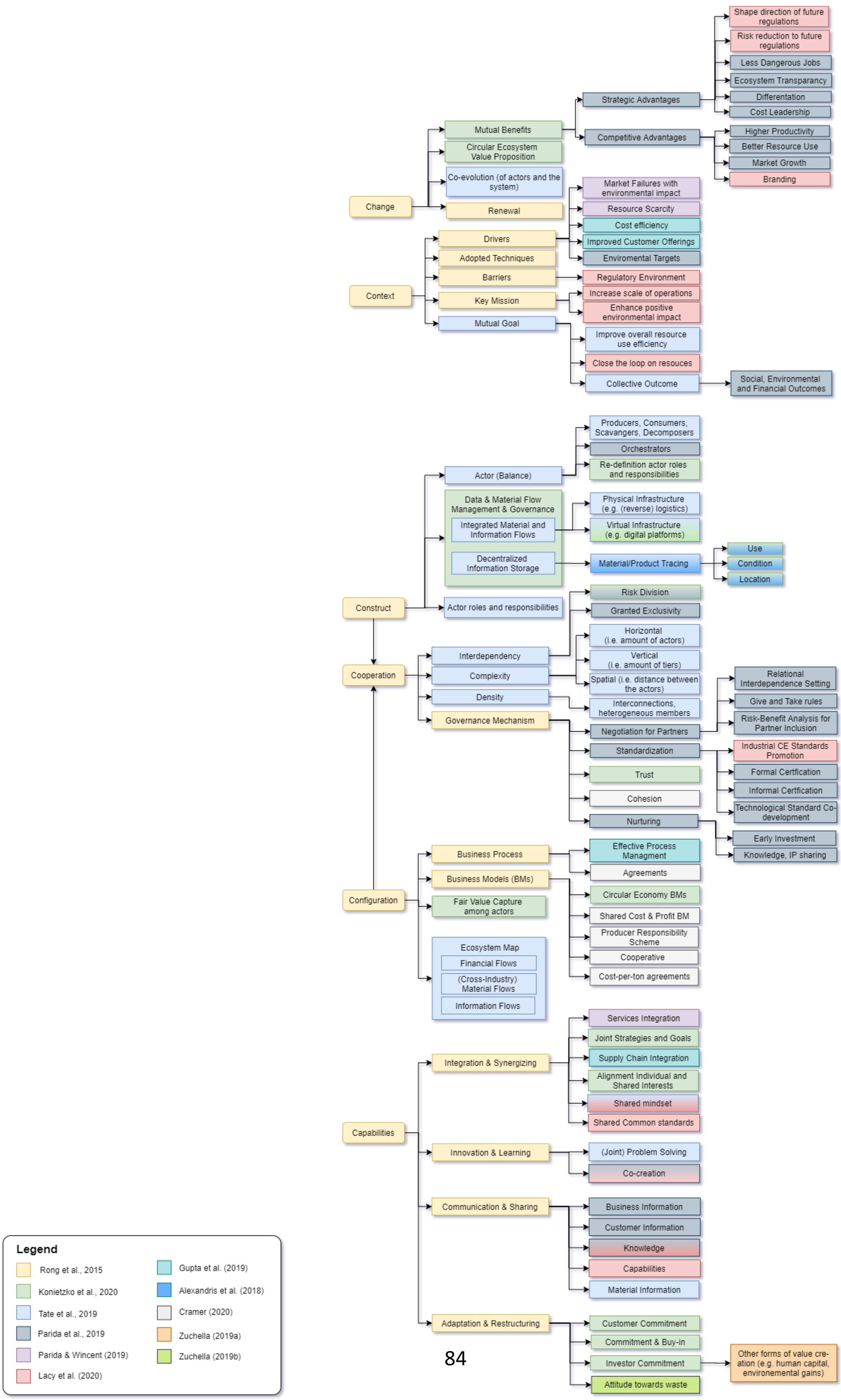
Parida, V., & Wincent, J. (2019). Why and how to compete through sustainability: a review and outline of trends influencing firm and network-level transformation. *International Entrepreneurship and Management Journal*, *15*(1), 1-19.

From snowballing of relevant articles

Wang, Y., Han, J. H., & Beynon-Davies, P. (2019). Understanding blockchain technology for future supply chains: a systematic literature review and research agenda. *Supply Chain Management: An International Journal*.

Parida, V., Burström, T., Visnjic, I., & Wincent, J. (2019). Orchestrating industrial ecosystem in circular economy: A two-stage transformation model for large manufacturing companies. *Journal of Business Research*, *101*, 715-725.

Appendix B. Map of article linkages to the 6C elements of Rong et al. (2015) framework



Appendix C. Interview Protocol

This appendix displays the interview protocol used in this research. In bold is "en houdingen" as this was added to the interview protocol during the second interview.

Name Interviewee
Quirien Reijtenbagh
Date
Time

Start: 8.30

(*Information provided before starting the interview*) (2 min)

Ik ben Quirien Reijtenbagh, ik doe de master Industrial Ecology aan Leiden Universiteit en TU Delft. In deze master kijken wij onder andere naar hoe materiaalkringlopen gesloten kunnen worden in de maatschappij. Vandaar mijn interesse in de circulaire economie.

Voor mijn onderzoek ben ik daarom benieuwd naar hoe een ecosysteem van partijen eruitziet die zich tezamen inzetten om de bouwmaterialenkringloop te kunnen sluiten. Aangezien bouwmaterialen ook in onderdelen zitten zoals deuren, vloeren, tussenwanden en kozijnen en gevels, behoort hergebruik of recycling van onderdelen ook tot de bouwmateriaalkringloop in mijn definitie. Met secundaire materialen bedoel ik dus alle bouwmaterialen en -onderdelen die werden "gewonnen of gemined of geoogst" uit de afgebroken gebouwen.

Mochten de vragen onduidelijk zijn, dan kan ik deze tijdens het interview toelichten. Het interview bevat 25 vragen, die in 60-70 minuten kunnen worden beantwoord. De laatste paar minuten van het interview gebruik ik om te kijken of al mijn vragen beantwoord zijn. Indien niet, dan heb ik nog tijd om de onbeantwoorde vragen alsnog te kunnen stellen. Ik zal de uitwerking van het gesprek naar u toe mailen binnen 14 dagen. Na uw akkoord hierop zal ik deze, louter en alleen, gebruiken voor mijn onderzoek. Verder zal ik uw bedrijfsnaam en eventuele projecten waarover wij te spreken komen, indien gewenst, anonimiseren. *Gaat u hierop akkoord? Mag ik dit gesprek ook opnemen?*

(*Background*) (3 min)

Wat zijn uw functies binnen het bedrijf geweest en wat is uw functie nu en wat houdt deze in?

Kunt u kort de geschiedenis van uw bedrijf toelichten, en wat waren en zijn de bedrijfsactiviteiten (Business Environment)?

(*Context*) (5 min)

Welke circulaire diensten en producten bent u gaan aanbieden om bij te dragen aan het sluiten van materiaalkringlopen? Sinds wanneer?

Waarom bent uw deze circulaire diensten of producten gaan aanbieden? (Drivers, Missions)

Wat bemoeilijkt het aanbieden van deze circulaire diensten en producten? Is dit per project anders? (Barriers)

Welke secundaire materialen komen zo weer terug de bouwketen in en hoe? Hoeveel was dit in een percentage uitgedrukt, schat u? (Matureness) Welke secundaire materialen belandden in een andere industrie? Wat is jullie visie hierop voor de toekomst? (Industry Vision)

8.40 (*Construct*) (10 min)

Welke partijen waren er aanwezig om de materialenketen in bouwmaterialen te kunnen sluiten en wat is uw rol en uw verantwoordelijkheid (Actor Roles)? Eigen notitie: bijv. een faciliterende en/of coördinerende rol? En wat waren de rollen van andere partijen?

Was er een fysieke infrastructuur nodig om de bouwmaterialenketen te kunnen sluiten (Physical Infrastructure)? Zo ja, welke? Bijvoorbeeld: opslag van materialen in loods, marktplaats, machines, bepaalde logistiek.

Was er een virtuele infrastructuur nodig om de bouwmaterialenketen te kunnen sluiten (Virtual Infrastructure)? Zo ja, welke? Bijvoorbeeld: online marktplaats, BIM, materialenpaspoort, *Was er sprake van dataopslag van de secundaire bouwmaterialen? Zo ja, welke informatie werd opgeslagen en hoe?* *Bijvoorbeeld: door middel van QR-codes of een Blockchain.*

8.50 (*Configuration*)

Welke activiteiten maakten het mogelijk om de bouwmaterialenkringloop te sluiten in een circulaire project (Sequence of Activities/Value Chain)?

Wat was de toegevoegde waarde voor u en de betrokken partijen om de bouwmateriaalketen circulair vorm te geven en zo te sluiten (Value Capture)? Was er hier ook sprake van winstdeling (Shared Benefits)?

9.00 (*Cooperation*)

Was er sprake van samenwerking in de circulaire projecten om de bouwmaterialenketen te sluiten, zo ja, kunt u deze onderlinge relaties kort beschrijven? (Relationships) - 2 min

Wat is belangrijk voor een goede samenwerking hierin? (Relationships) - 1min

Hoeveel partijen waren er gemiddeld betrokken om de bouwmaterialenkringloop te kunnen sluiten in een circulair project (min-max) (Density)? - 2 min

Was het sluiten van de bouwmaterialenkringloop lokaal, regionaal, nationaal of internationaal georiënteerd (Complexity)? - 1 min

Zijn er partijen onderling afhankelijk van elkaar bij het sluiten van de bouwmaterialenkringloop? Bijvoorbeeld door een bepaalde risico-verdeling of onderlinge afspraken. Meer specifiek vanuit uw rol: van wie was u afhankelijk en wie van u? (Interdependency) - 2 min

Ontwikkelde of bedacht u (eventueel samen met de betrokken partijen) bij het sluiten van de bouwmateriaalkringloop, nieuwe diensten, producten, technologieën of standaarden of regelgeving met betrekken tot circulariteit of bent u dit van plan (Standardization, Nurturing)? - 3 min

9.10 (*Capabilities*)

Was er sprake van informatiedeling en kennis en/of kunde deling in de projecten? Zo ja, hoe vond deze plaats *(Information and Capabilities Sharing*)? - 2 min

Deelde u een gemeenschappelijke visie of doel met de partijen met wie u samenwerkte in deze projecten? Zo ja, welke? (Joint Strategies & Goals) - 2 min

Was er sprake van co-creatie of gezamenlijk problemen oplossing (Co-creation & Problem Solving)? - 2 min

Welke competenties ***en houdingen*** *van de betrokken partijen maakten het mogelijk om de bouwmaterialen-kringenloop succesvol te kunnen sluiten (Capabilities & Attitudes)? - 2 min*

In hoeverre was de bereidheid van klanten om te kiezen voor secundaire materialen belangrijk (Commitment)? En in hoeverre die van investeerders? - 2 min

9.20 (*Change*)

Heeft u het idee dat uw een competitief en/of strategisch-voordeel heeft gekregen sinds u de circulaire diensten of producten bent gaan aanbieden (New Advantages)?

Hoe verschilt de rol van uw bedrijf binnen een circulair project, van een regulier project? En hoe verschilt de samenwerking met de betrokken partijen? (Change in Roles & Collaboration)

Hoe verandert de rol van uw bedrijf bij toekomstige opschaling van grootschalige circulaire projecten, zowel in omvang als in hoeveelheid? Hoe verandert de samenwerking dan met de betrokken partijen? (Change in Roles & Collaboration)

9.30

Heeft u eventueel partijen waarmee u (heeft) samenwerkt die ik mag interviewen? Is er nog andersoortige informatie over uw circulaire projecten en uw rol hierin, welke van belang kunnen zijn voor mijn onderzoek, mag ik deze gebruiken? Bedankt voor het interview!

Mag ik u eventueel nog benaderen voor mijn onderzoek, indien noodzakelijk.

Appendix D1. Code scheme adaptations

Besides the examples of code addition Attitudes, Drivers and Barriers mentioned in the chapter "Methodology", other codes were added during the coding process. It occurred from the interview data that all orchestrated routes to high value reuse and recycling progressed through a trial-of-error process of development. For example, small-scale projects or pilot projects helped the demolition contractors to experiment with certain forms of material recycling and component refurbishment. **Trial-and-Error** was added next to Co-creation and Problem Solving to explain the subcategory Innovation & Learning. Also, the code **Process Change** was added, because process changes were needed to make achieve high value reuse and recycling now and in the future. The codes Anticipated Role Change and Anticipated Change in Collaboration did not fit the descriptions of all these process changes. This process changes for example involved description on reshaping and reconfiguring value chains, as these involve creating alternative material treatment routes. The needed material handling process differs in these circular routes in comparison to regular routes. Hence, this is considered rather a pattern shift in processes than a collaboration pattern shift (solely). Figure 1 displays all adaptations to the original code scheme of Rong et al (2015) that was used to analyze Internet-of-Things (IoT) business ecosystems.

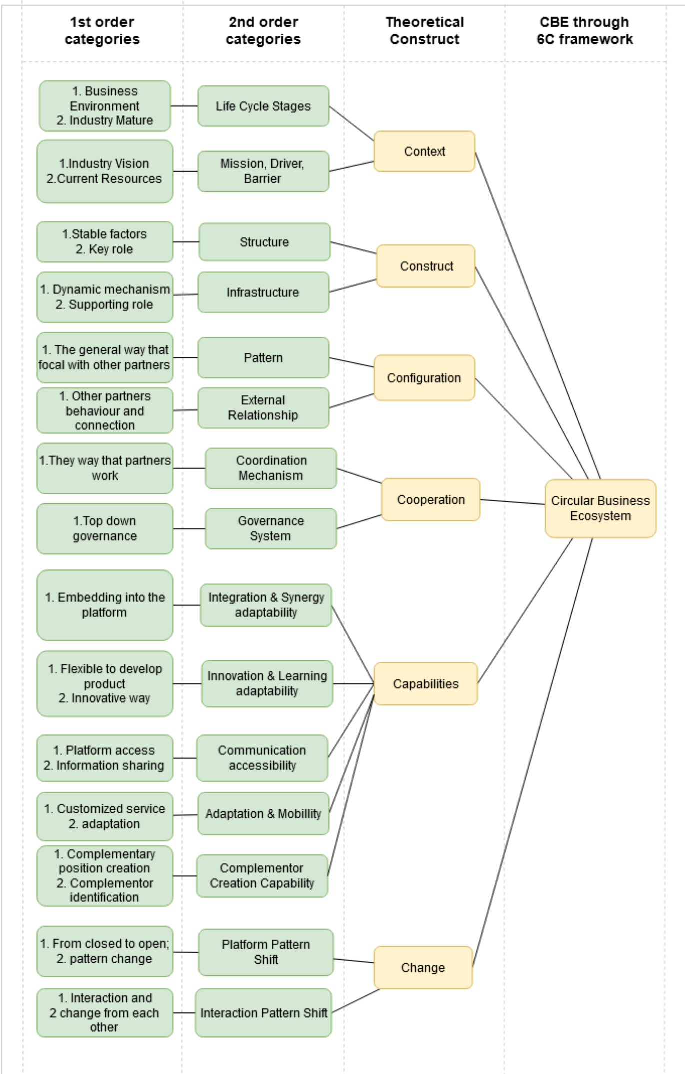


Figure 2. Original code scheme used by Rong et al. (2015) to analyze IoT-business ecosystems

Appendix D2. All codes explained

Activities/Services Integration:
Literature suggests that integration is important for a circular business ecosystem as supply chain integration can be useful for optimization (Gupta et al., 2019). Also, the integration of services across ecosystem actors may be helpful to generate most environmental benefits and highest customer value (Parida & Wincent, 2019).

Actor Roles:
Actor roles contain the roles, activities and responsibilities of actors (Konietzko et al., 2020a).

Adaptations:
Adaptations required by ecosystem actors to accomplish circular operations.

Alignment:
Alignments as a code refers to goals and strategy alignment, as mentioned by Konietzko et al. (2020a).

Anticipated Change in Collaboration:
As business ecosystems evolve over time this also is expected to involve changes in collaborations. Therefore, this code is added.

Anticipated Role Change:
Actor roles evolve over time. How these are expected to change to fulfill the ambitions of high value reuse and recycling is captured in this code.

Attitudes:
This code was added during the interviews because of the importance of certain attitudes that the interviewees mentioned. With attitudes is meant the way of acting.

Business Environment:
The business environment entails all internal and external factors that impact the business operations. This for example includes governmental decisions, laws, trends, competitive parties, and customers.

Business Process:
This code involves the subsequent activities are needed to achieve high value recycling and reuse.

Capabilities sharing:
Knowledge sharing and intellectual property to achieve the collective outcome (e.g. circular economy targets) (Parida et al., 2019). Parida et al. (2019) found core knowledge sharing is needed to nurture the circular business ecosystem. The effectiveness of collaboration is highly due to **capabilities** and **knowledge** distribution (Lacy et al., 2020, p.289).

Co-creation:
Co-creation is a value created by interaction between companies and active product' users by sharing capabilities and resources (Arnold, 2017). In an ecosystem, co-creation can take place between cross-industry ecosystem partners (and customers) to solve circularity problems (Lacy et al., 2020, p.297) and exploit sustainability gains together (Parida & Wincent, 2019).

Commitment:
From the literature followed that different forms of commitment are necessary in a circular business ecosystem. Konietzko et al. (2020a) observed that customer commitment is important to a circular ecosystem. In addition, business and customers should change their **behavior towards waste** (Zucchella, 2019b, p.198). Investment commitment is also regarded as important.

Competitive advantage:
Competitive advantages are those advantages that makes the company preferable above other companies to work with. There are certain competitive advantages related to operating in a business ecosystem, like mentions higher productivity, better resource use and market growth that can reduce costs and create profits (Parida et al., 2019). Another competitive advantage mentioned is branding (Lacy et al., 2020, p.291), as active

ecosystem actors can signal their leadership and commitment to customers, investors, media, and future employees.

Current Resources:
The company's resources are those resources that are used to create value to customers or clients and conduct the business operations. This can be physical resources like machinery and transport, human resources like experienced employees or certain in-house expertise, intellectual resources like intellectual property, and financial resources like loans and money.

Density:
Density is in this study focused on the locality of actors that were needed to establish high value reuse and recycling of building materials. To not overload the complexity of this research the options of characterization are local, regional, national, or international. So, with density here is meant: the character of the physical distance between the actors involved. It also describes the number of actors involved in the ecosystem.

Heterogeneity:
Heterogeneity is valuable having varied and complementary resources in an actor network generate innovation and application thereof (Corsaro et al., 2012). According to Corsaro et al. (2012) various and different actors are generally involved in innovative practices. Heterogeneity concerns the number of different actors, as they bring different capabilities and knowledge to the network.

Industry Vision:
Industry Vision is about the company thoughts on how the C&D industry could be in the future with respect to high value reuse and recycling.

Information/data sharing:
Tate et al. (2019) mentions that also data transparency on material information helps to estimate the value of materials for potential take back and material recovery options. This code captures all data and information shared. Parida et al. (2019) that sharing business information (e.g. intellectual property) is important for nurturing the ecosystem.

Interdependency:
Parida et al. (2019) describes the relational dependence in more economic terms as: profit sharing and purchasing arrangements, granted exclusivity, risk division (Parida, 2019). Interdependency is regarded as a characteristic of natural ecosystems (Tate et al., 2019)

Joint Strategies & Goals:
Common strategies and goals development is important to set directions that every ecosystem actor acknowledges (Konietzko et al., 2020a). The development of common strategies and goals is important to develop a common language, create a goal and strategies alignment and a shared feeling that the innovation can really succeed (Konietzko et al., 2020a).

Matureness:
Matureness can be defined as the stage in which the company operates with respect to circularity. The matureness of the lifecycle stages is based on Moore (1993) as birth, expansion, and leadership. The self-renewal phase has started already for the companies, but some have evolved more than others in sustaining circular secondary building material supply.

Nurturing:
Thus, ecosystem orchestrators must actively invest and show the path for ecosystem partner companies to achieve circular business models. In the multi case study analysis of manufacturing companies from Parida et al. (2019) nurturing elements by the orchestrator were found to be: early investments making, novel process development with certain partners, knowledge and intellectual property sharing.

Physical Infrastructure:
This optimization relates to the physical infrastructure as this concern for example logistics.

Problem Solving:
Tate et al. (2019) further highlighted the need to find ecosystem actors with complementary capabilities that can work jointly to solve problems (e.g. the breakdown of a complex product to its materials). The different ecosystem actors will bring their own problem-solving approach that lead to new angles to tackle a problem (Konietzko et al., 2020a).

Process Change:
Process changes were needed to make achieve high value reuse and recycling now and, in the future,

Relationships:
Circular business models are characterized by collaboration to execute these (Lüdeke-Freund et al., 2019). The code relationships describe the forms in which the actors in the circular business ecosystem collaborate.

Shared Advantages/Mutual Benefits:
Mutual benefits are those benefits that are realized for other ecosystem actors as well, including benefits to customers that need to embrace the ecosystem's innovation.

Standardization:
Parida et al. (2019) found that standardization is a means to implement circular economy practices. The process of standardization refers to activities and investments carried out to formulate industry requirements that help to accomplish the circular business case. Parida et al. (2019) found as standardization strategies: informal standardization e.g. non-legally industry standards, technological standard co-development, and formal certification.

Strategic advantage:
Strategic advantages are expected future (competitive) advantages because of certain actions nowadays. Examples are of strategic advantages mentioned in literature are differentiation (Parida & Wincent 2019), risk reduction to future regulation and shaping regulations (Lacy et al., 2020, p.291)**.**

Value Capture:
Value capture describes how earnings are retrieved from the product or service delivered. This is an important part of the business model as described by Osterwalder & Pigneur (2008).

Value Creation:
This code is specifically focused on how value is created for society and the environment as well. Societal and environmental value creation are associated with the circular economy (Leising et al., 2018). For example, in the case of social value creation in the circular economy authors sometimes mention job creation (Geissdoerfer et al., 2017). For environmental value creation, one may think of environmental impact reductions, like reducing carbon emissions and pollutive practices.

Virtual Infrastructure:
The virtual infrastructure is any infrastructure that is not physical but support the ecosystem activities. Following Konietzko et al. (2020a) a **virtual infrastructure** in a circular ecosystem can be an online platform that consist of a virtual market and physical assets that are offered at the platform.

Appendix E. Summary of findings per codes

Dimensions	2nd order category codes	1st order category codes
Context: *environmental features of the circular supply network*	**Life Cycle Stages** *of the degree of circularity*	**Business Environment:** - increasing number of clients with circularity ambitions - diverse range of buildings and building materials applied - secondary building materials compete with their (often low-priced) counterparts - circular projects currently cost more time, effort, and manpower than regular projects - increased willingness to exchange ideas on circular practices in the demolition sector **Matureness:** - several routes to higher value reuse and recycling or constructed for different components (e.g. suspended ceilings, wooden beams) and materials (e.g. gypsum and concrete) - the number of higher value recycling and reused achieved in mass percentages on average differed per company and ranged from 1-20% - several new routes to higher value reuse and recycling are currently explored by the companies (e.g. sanitary, other wood types, carpet tiles, masonry)
	Drivers, Barriers, Mission *of the ecosystem*	**Industry vision:** - more projects are expected to involve circularity (especially tenders from governmental bodies) - traditional competitive mindset should be abandoned - more collaboration across C&D actors - having the same vision of minimizing waste and minimizing number of new materials applied in construction projects **Current Resources:** - standard dismantling approaches of easy-to-dismantle components that can be resold or refurbished - more than standard dismantling can be offered upon the client wishes (e.g. early-contractor collaborations, selective dismantling) - cross-disciplinary technical and regulatory knowledge in case of direct application of salvaged building materials in a construction project **Drivers:** - intrinsic logic to recover materials when environment and society benefits - anticipation to regulations like carbon taxes or waste bans - financial benefits **Barriers:** - opaque sales market for secondary building materials - limited material inventory time in pre-demolition phase - dismantling practices take more time and are more costly than regular demolition practices - absence of (grounded) standards to signal circularity/ environmental impact of secondary building materials - it is difficult to provide certificates and guarantees to secondary building materials - specific tender requirements leaving no room for creativity - reasonable transport distances - matching supply and demand of salvaged building materials
Configuration: *activities in circular supply network and how these form configuration patterns*	**Business Process** *of the supply network in the ecosystem*	**Sequence of Activities/Value Chain:** - the circular business ecosystem of all companies exists of several ecosystem orchestrations, value chains and early-contractor collaborations - there are two main configuration patterns: direct application of salvaged materials in a new construction project and. - orchestrated value chains to resell salvaged materials for reuse (e.g. at online marketplaces) or refurbish (e.g. wooden beam

		refurbishment).
	Business Models *of the supply network in the ecosystem*	**Value Capture:** - salvaged materials themselves are costless, however the retrieval from the building and refurbishment is costly - earnings are retrieved from either saving material costs when applied to another project, or from reselling or selling refurbished building materials **Value Creation:** - social value if SROI labor is used for refurbishment practices - environmental value by avoiding primary material use and prolonging material use - esthetic value for those who appreciate the salvaged material application to new buildings
Construct: *infrastructure and structure of a circular business ecosystem*	**Structure** *of the ecosystem*	**Actor Roles:** - Academia for research support - Architects to design from salvaged materials - Building contractors for calculating and as a logistic partner in refurbishment hubs - Clients to demand projects with circular ambitions - Demolition contractor for orchestrating value chains or direct reselling of materials, for dismantling practices, building materials inventory and data processing, for internal reuse and recycling - Engineering and Advisory Companies for material testing, data management and facilitating matchmaking of supply and demand - Independent party as a connecting factor in circular C&D projects - Other customers: Private Individuals and Companies that apply salvaged materials in their buildings - Producers for product take-back and recycling/refurbishment of products or to use salvaged materials in production process - Recyclers for recycling to secondary products or raw materials - Social enterprises to provide SROI labor - Spokesman in an advocacy role for tenants in circular C&D projects - Wholesalers for retail of refurbished building materials
	Infrastructure *of the ecosystem*	**Physical Infrastructure:** - physical infrastructure (e.g. logistics, storage) differed per route to higher value reuse and recycling - only the online marketplace without storage does not have any physical infrastructure - some routes needed a physical location for storage and reselling close-by the company's facilities - refurbishment chains always include a refurbishment hub - some mobile devices are needed to close the loop locally on project level (e.g. smart crusher for concrete) **Virtual Infrastructure:** - tablet use to support building materials inventory in the pre-dismantling phase, registering materials specifications, release time and date and building location - online innovative circular platform where this data is collected and an online marketplace is offered - use of material passports to store information on building materials present in the current building stock. - QR-coding of secondary building materials
Cooperation: *collaboration and governance mechanisms of the circular business ecosystem*	**Network Characteristics** *of the ecosystem*	**Interdependency** - on consumers and building contractor's willingness-to-purchase - on developments in other industries that produce (raw) building materials - on the client's (circular) ambitions - on time provided by the client to dismantle the old building - on the current market for salvaged materials

		- on possible matchmaking of old buildings to construction projects. **Density** - value chains for materials are closed locally, regionally, nationally or even internationally (only Belgium mentioned) - locally closing the material loop is preferred as longer value chains are less cost and environmentally efficient - in circular C&D projects around 4-5 actors are present - orchestrated value chains can have multiple demolition companies as participants, but do not necessarily. They can also be orchestrated together with building contractor(s) **Heterogeneity** - in circular C&D projects the core actors are client, demolition company, building contractor and architect, but can also be extended with other different parties (e.g. spokesman, construction engineer), but less than 10. - value chains have a smaller group of actor types, either 2: demolition contractor(s) & wholesaler(s) or reseller(s) or; demolition contractor(s) and building contractor(s) or; demolition contractor(s), recycler(s) and producer(s)
	Governance Mechanism *of the ecosystem*	**Relationships:** - a consortium for high-quality recycled concrete - early-contractor involvement collaborations in circular C&D projects like a consortium, management team (in Dutch: regieteam) or construction team (in Dutch: bouwteam) **Standardization:** - efforts to connect refurbished or recycled materials and components to existing certification schemes **Nurturing:** - virtual infrastructure to share ideas and engage parties to develop or join circular value chain development - provide a positive feeling from reused or recycled components for buyers and clients - constantly focus on buyers of salvaged materials - creating a database that connect future demolition projects to new construction projects - seeking producers to ideate about take-back options - discuss circular operations, even though the client may initially ask for traditional demolition
Capabilities: *capabilities used in the circular supply network*	**Integration & Synergizing** *of circular operations in the ecosystem*	**Joint Strategies & Goals:** - circular C&D projects have a common end goal and working together towards achieving that goal is important, as well as; - collaboratively decide what is feasible in terms of technicality and costs **Services/Activities Integration:** - virtual (e.g. online marketplaces) and physical infrastructure (e.g. physical marketplaces) can be shared - infrastructure of value chains are shared e.g. refurbishment hubs - creating a database that connect future demolition projects to new construction projects - temporary on-site material storage in old buildings in the case of local C&D projects - **Alignment:** - alignment of personal gains with achieving common circularity goals set in circular C&D projects - alignment of personal effort with (extra) common effort made to achieve common circularity goals set in circular C&D project
	Communication & Sharing *between ecosystem participants to carry out circular operations in the ecosystem*	**Information/Data Sharing:** - sharing information about their barriers and progress on circularity in developing value chains - transparency on available budgets, cost, and earnings of all circular activities both in value chains as in circular C&D projects **Capabilities Sharing:** - relevant knowledge (e.g. technical knowledge, guarantees), skill

		and experience sharing in C&D projects and value chain set-ups
	Innovation & Learning *that takes place in to carry out circular operations in the ecosystem*	**Co-creation:** - joint efforts on how salvaged building elements or components can be used for new (or previous) purposes - joint efforts on establishing refurbishment chains with other parties - also, joint learning can be explicitly part of a circular C&D project **Joint Problem Solving:** - shared circular ambitions require shared problem solving: if more time is needed, than this is automatically a shared problem - jointly make architectonic and cost considerations - joint problem solving on hampering regulations and guarantees **Trial-and-error:** - refurbishment chains development shows a pattern of trial-and-error: first piloted, involving only partners, then - if successful - opened to other parties and then optimized (e.g. by electrifying transport) - learnings from trialing circular operations in previous and pilot projects are used to optimized circular operations in other (larger) projects.
	Adaptation & Restructuring *that is required to carry out circular operations in the ecosystem*	**Commitment:** - governmental bodies as clients are steered from national ambitions to include circularity in tenders - commitment of the client is needed for circular ambitions, this can also involve investor commitment (if the investor is the client) - commitment involves the willingness to engage in collaborative trajectory and be enthusiastic about it - commitment of contractors to build with secondary building materials - commitment from building material producers to change their value chain e.g. by including more recycled content in their products or using take-back schemes - smaller parties are generally more flexible and motivated to work with salvaged materials **Adaptation:** - adaptation to providing openness about prices and techniques - gaining trust in each other ('s intentions) - be more flexible than in traditional projects - be(come) enthusiastic and feels like investing time and effort **Attitudes:** - daring, open, flexible, cooperative, and transparent attitude
Change: *the process of shifting from one supply network to a circular supply network*	**Roles Shift** *that is required to shift from linear to a circular supply network in the ecosystem*	**Anticipated Role Change:** - more dismantling practices - active role of demolition contractors in finding and developing solutions to circular material processing - an advisory role for the demolition contractors in the beginning of C&D projects on how to build (for deconstruction) and; - a material inventory role on what salvaged materials are available - potential role for banks to provide loans to the building rather than the owner to stimulate circular material choices
	Pattern Shift *that is required to shift from linear to a circular supply network in the ecosystem*	**Anticipated Change in Collaboration:** - change to a model that allows for early contractor involvement in the beginning of the circular construction and demolition project - collaboration with clients to create a database for matchmaking of demolition to construction projects **Process Change:** - old value chains require business process changes to enhance the chain to higher value reuse or recycling - tailoring of more careful dismantling practices to (new) value chains and circular ambitions in C&D projects (e.g. by robotic operations) - virtual registering materials of to-be demolished buildings

	New Advantages *that provide the shift to circular operations in the ecosystem*	**Competitive Advantage:** - parties involved can use their experience in circular C&D projects and their value chains in offerings to clients or for further value chains development. - parties involved attracts parties who are also affiliated with sustainability like municipalities, housing corporations, universities **Strategic Advantage:** - parties involved anticipate future returns on circular practice investments when future regulations will be effective (e.g. carbon tax, only circularity tenders by 2030). **Shared Advantages/Mutual Benefits:** - within a value chain each actor gets a fair share - lesson-learned together can be of value to future circular project involvement