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6th of July, 2018

Component Reuse in Construction

The current building stock as a source of components for new buildings

Master's Thesis
Delft University of Technology

Colophon

Graduation Master's Thesis

AR3R010 Graduation Laboratory - Circular Economy

Architecture, Urbanism, and Building Sciences
Management in the Built Environment

July 6th, 2018
TU Delft

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Images

"In the highly developed economies of the future, it is probable that cities will become huge, rich and diverse mines of raw materials. These mines will differ from any now to be found because they will become richer the more and the longer they are exploited."

Jane Jacobs (1970)

Preface

Writing a thesis is quite an undertaking that I could not have done alone. This thesis was written with the help of many people to whom I would like to express my gratitude.

First of all, I would like to thank my first supervisor, Matthijs Prins for his hours long discussions that always challenged me to look deeper. My Second supervisor John Heintz, who helped to keep me on track and always pushed me to go the extra mile. And my third supervisor Ellen van Bueren, whose passion for the subject helped me retain my enthausiasm throughout the research, while her prowess for research has allowed me to sharpen the methodology significantly.

Many thanks go to Astrid Potemans, for sharing many interesting discussions over many cups of coffee. Lastly, I would like to thank the companies involved in the case studies that are part of this research. In particular the following people have been very helpful and given up their time to help me further the research: Rob Gort, Lionel DeVlieger, Barthel van Dinther, Andreas de Heij, Bert Albers, and Taco van Iersel.

Luuk Gremmen
June 29th, 2018

Summary

Introduction

Circular building has been increasing in popularity over several years. The idea being that we should not use resources only once and then discard them but continue using them in new products. More broadly the world is moving from a linear economy to a circular economy. A circular construction industry is just one part in this bigger transition. Where buildings differ from most other product categories is in the long lifespan of individual buildings. This requires a different approach to circularity than for products with a short life cycle. The short turnaround of consumer products means that the move to a circular production process could, at least in theory, be achieved in a short time. Circularity in the built environment is a different story altogether, while building new circular buildings will help achieve a circular economy in a hundred years' time, the stock of current buildings should not be forgotten. Urban mining, that is mining from technospheric stocks, can be used to incorporate resources currently in use in existing buildings into the circular economy.

To extract resources from buildings that were not designed for deconstruction information is required on the quantity and quality of these resources. In research on urban mining this is often interpreted as a need for prospecting large areas of urban areas and conducting a mineral exploration. The aim of this study is to look at the micro-level of single buildings and building components to find drivers and barriers that encourage or inhibit circular demolition and component reuse, as well as identifying opportunities for entrepreneurs and policy makers.

Keywords: circular economy, urban mining, circular demolition, deconstruction, component reuse, exploratory, case study

Relevance

In the transition towards a circular building industry the focus is usually put upon new buildings designed for deconstruction. This research approaches the challenge of transitioning to a circular building industry from the side of the current building stock. Since little research has been done into component reuse for components reclaimed from current buildings this exploratory research can be useful for entrepreneurs trying to exploit this opportunity, policy makers aiming to stimulate component reuse, and researchers doing further research.

Many barriers have been overcome already by pioneers in the field of circular construction, while others have yet to be overcome. A comprehensive scientific approach is thus far lacking. The aim of this research is to explore the different drivers and barriers that have been experienced by professionals, trying to reclaim components or construct buildings using them. This research will be limited to the construction sector and the focus on reuse of components, rather than recycling of materials is what sets it apart from existing research.

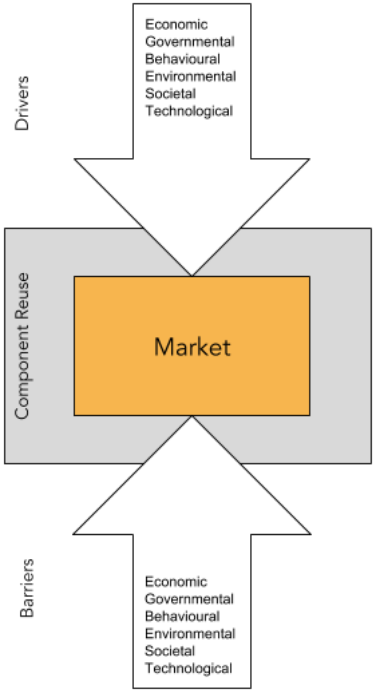

Figure A: Analytical Framework.

Methodology

This research has an exploratory objective and therefore requires a research method that maximises exploration possibilities. A holistic and qualitative approach is taken to analyse four cases (Kumar & Phrommathed, 2005) in a multiple case study (R. E. Stake, 2006). A methodological framework for finding drivers, barriers, and opportunities (Engelken, Römer, Drescher, Welpe, & Picot, 2016; Iacovidou & Purnell, 2016) for circular demolition and component reuse is developed based on the six dimensions of research into circular economy in the built environment (Pomponi & Moncaster, 2016). This analysis is used to answer the following research question:

What are the current drivers, barriers, and opportunities for circular demolition and the integration of component reuse into new buildings in the Benelux?

The research consists of three parts that together answer the research question. The parts are:

1. Analysing the cases
2. Finding drivers and barriers for circular demolition and component reuse
3. Identifying opportunities for circular demolition and component reuse

The cases have been selected based on their relevance to both demand and supply sides of component reuse, a summary of the cases is given in table 1.

Findings

	Van Liempd	Bouwcarrousel	Rotor DC
Facilitator	Van Liempd is a circular demolition company, that sprung from the traditional demolition industry. They use proven methods of demolition in combination with their experience to increase the number of components that can be reused.	Bouwcarrousel was a company with a business model of identifying, extracting, and selling used building components. In its ten years of existing it has been involved in many successful projects. Ultimately the low demand for reclaimed components led to bankruptcy.	Rotor DC is a company set up by architects to make use of components freed by the demolition of buildings. They facilitate the reuse by identifying and extracting components they believe to have value.
		Erasmus MC	**Government Real Estate Agency**
Client		Erasmus MC is the academic hospital in Rotterdam. As part of their transformation plans a new building is constructed and two old buildings are demolished. The demolition of these buildings is seized by the organization as a chance to demonstrate their corporate values by attempting to reclaim components.	The Central Government Real Estate Agency (RVB) is the real estate division of the national government. From this role they take the lead in practices of circular construction and have recently finished their first circular demolition project.

Table A: A summary of the cases.

Many drivers and barriers for component reuse in the construction industry have been identified. The drivers and barriers have been placed in six dimensions. It has been found that the drivers for circular demolition mainly belong to the environmental, behavioural, societal, and governmental dimensions. Not many barriers for circular demolition have been identified, suggesting that there are many opportunities to be exploited on the demolition side of the equation. Barriers for component reuse are more plentiful and include behavioural and societal barriers such as the perception that reclaimed components are of inferior quality. Where circular demolition has strong drivers in the governmental dimension, in the form of hard limits set on construction and demolition waste and plans to reduce this in the future, there is no such incentive for component reuse. Setting up a policy of this kind could be an opportunity to overcome the strong barriers. come without a shift in behaviour, but this is creating opportunities for policy makers to develop the right legislation.

Conclusion

A number of drivers and barriers have been identified. The drivers and barriers for circular demolition are different from those of component reuse. Circular demolition benefits from broader acceptation in the industry, thus having drivers in the societal and behavioural dimensions as well as in environmental and governmental dimensions. There are technological opportunities to increase efficiency, but no significant technological barriers have been found. The principal barrier to circular demolition is the limited of demand for reclaimed components, but interestingly enough at the same time a limited supply of identical high-quality components prevents adoption among businesses. There are mayor barriers to component reuse in the behavioural and societal dimensions; i.e., there is a negative association with second hand materials and the organisational structure of companies is not set up to accept reclaimed components. The lack of economic and governmental drivers mean that these barriers are unlikely to be overcome without a shift in behaviour, but this is creating opportunities for policy makers to develop legislation that as of now does not exist to stimulate component reuse, but only to stimulate waste minimisation.

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Introduction

"Imagine an economy in which today's goods are tomorrow's resources, forming a virtuous cycle that fosters prosperity in a world of finite resources."

(MacArthur, 2013)

1.1 Problem Statement

Our society and economy are constantly changing. The way we produce things, however, has not changed since the beginning of the industrial revolution two centuries ago and resulted in scarcity, depletion and waste of resources, environmental pollution and climate change (MacArthur, 2013). Our economy is based on a linear system which contains make-take-dispose consumption. Current and future developments show that the demand for natural resources will have increased threefold by 2050. Causes underlying these developments are on one hand the growth of the world population, from 7 billion people today to 9 billion people in 2050, and on the other the global economic growth in prosperity (Swilling, 2011). During the same period, 3 billion people will be added to the middle class, which leads to an expected doubling of consumption per capita (WBCSD, 2008). Due these developments, improving the quality of life for many is in jeopardy (MacArthur, 2013). Circular economy (CE) is a recent way of looking at sustainability, based on thinking in circular supply chains, maximizing the value of materials in which products can be reused, remanufactured or/and recycled (MacArthur, 2013). The built environment is responsible for using up to 50% of the raw materials and contributing up to 30% of the waste flow in the European Union (Uihlein & Eder, 2009). To allow for the recycling of materials used in the built environment, there is a trend towards circular building a method in which buildings are designed in a way that allows the materials used to construct the building to be reused (ABN, 2014). However, a substantial share of the stock in Europe is older than 50 years with many buildings in use today that are hundreds of years old (Economidou et al., 2011). This begs the question, what about the existing buildings? Let us take the UK building stock as an example, the expansion of the building stock and built infrastructure takes place in most areas at 1 to 2% per year. This means that up to 75% of the dwellings in existence in the year 2050 have already been built (Ravetz, 2008). This knowledge makes the reuse, re-manufacturing, and recycling of materials and parts from the existing building stock a more pressing problem than the design of new circular buildings, that have a potential lifespan of decennia.

1.2 Knowledge Gap

Initiatives from the construction industry with the mission to design circular buildings have been popping up left and right. This results in the development of many buildings that claim to be circular, and while not all of these claims are equally valid these developments demonstrate a steady progress towards circular building. Similarly, academic research to better understand the details of a circular building stock is growing, but many angles of circular building are still insufficiently explored. Very little attention has been paid to the intersection of reclamation and reuse (Adams, Osmani, Thorpe, & Thornback, 2017), this is where the focus of this study lies (figure 1.1).

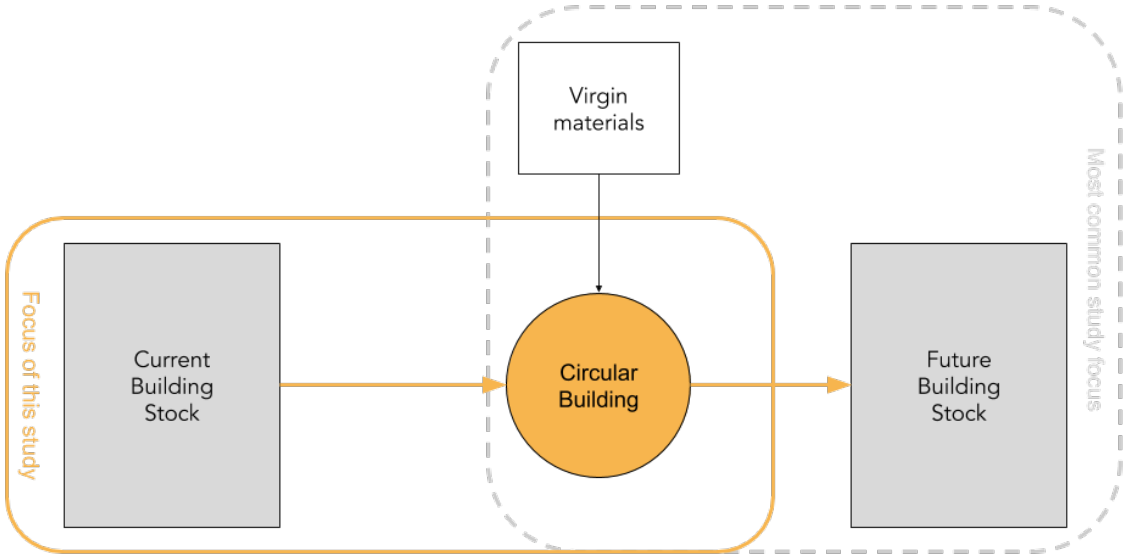

Figure 1.1: Focus area of this study.

1.3 Objectives of this Research

This study aims to bridge the gap between the recovery and reuse of used building components recovered through urban mining. This will be achieved, by exploring cases situated on the overlap between supply and demand sides from the industry to find drivers and barriers for component reuse, as well as identifying opportunities for achieving a circular supply chain. The synthesis of the findings will help gain new insights in the supply chain interactions necessary to connect the current building stock to a future circular building stock.

1.3.1 Intended product

This study contributes to the small body of work that has thus far dealt with the practice of urban mining, or more specifically component reuse. Its value lies in the linking of theoretical knowledge with practical application. This is relevant for policy makers attempting to stimulate the adaptation of circular economy, like the national government of the Netherlands (Schut, Crielaard, & Mesman, 2016), market parties active in the demolition of buildings, and it can also be relevant for researchers to gain insights in the possibilities of reusing reclaimed building components. The intended product is an exploratory study, establishing the current drivers, opportunities, and barriers of component reuse systematically analysing them to benefit future developments.

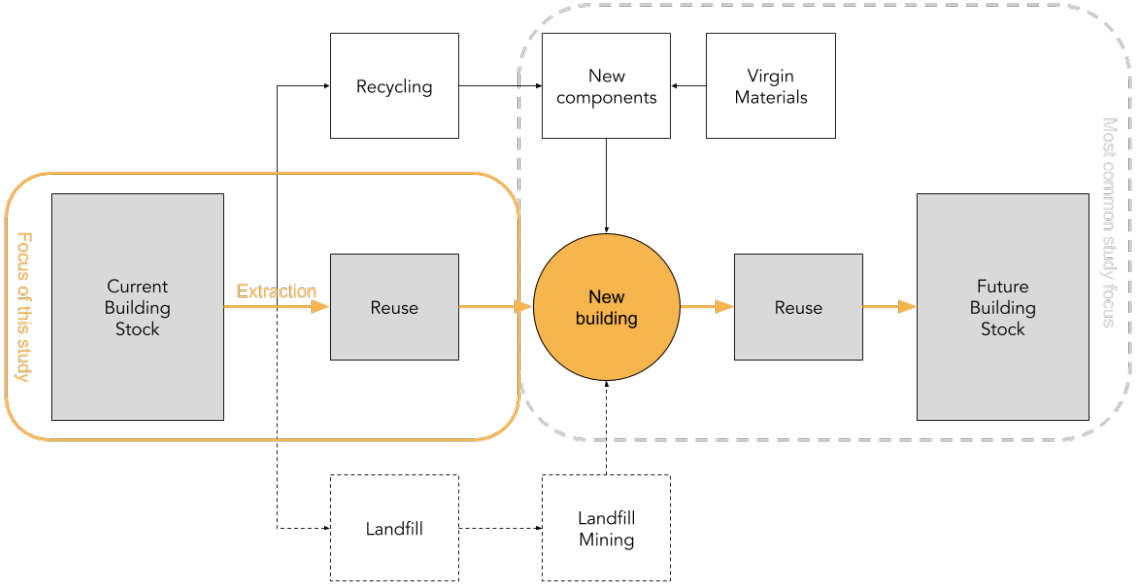

Figure 1.2: Focus area of this study in more detail.

1.4 Research Questions

In her book 'the economy of cities', Jacobs (1970) predicted the rise of urban mining at the basis of a circular economy by stating: 'In the highly developed economies of the future, it is probable that cities will become huge, rich and diverse mines of raw materials. These mines will differ from any now to be found because they will become richer the more and the longer they are exploited.'. The goal of this research is to find the drivers, barriers, and opportunities to realising this vision by answering the following main question:

What are the current drivers, barriers, and opportunities for circular demolition and the integration of component reuse into new buildings in the Benelux?

1.4.1 secondary research questions

The following secondary research questions have been formulated to guide the research towards the answer of the research question.

1. What can current cases reveal about the drivers and barriers of reclaiming building components from existing buildings?
2. What can current cases reveal about the drivers and barriers of integrating reclaimed components into new buildings?
3. Which opportunities for component reuse can be found in current cases?

By answering these questions this study attempts to

bridge the knowledge gap between the demand and supply side of the reuse of construction materials and explore opportunities for encouraging or facilitating component reuse in the construction industry.

1.4.2 current state of research

Many individual projects have been started with the goal to make the reuse of materials possible in the construction sector. Enthusiastic individuals have set up companies that collect reusable components and materials, developers have built single buildings sourced from secondary materials, and architects have designed buildings that can be fully disassembled for reuse. On the academic side of the coin the main pursuit thus far has been to build databases of future resources. These databases differ in scope and name but can largely be categorised as one single type of research. This study aims explore drivers, barriers, and opportunities for component reuse. According to Engelken, Römer, Drescher, Welpe, and Picot (2016), 'such an overview is important for researchers and policy-makers for designing the right legal and policy frameworks.' Considering the state of current research, no attempt will be made to design a supply chain model for component reuse. Rather the goal is to explore the opportunities by casting the net wide and studying different projects that have successes or failed projects. The drivers, barriers, and opportunities encountered in these projects can serve as a learning experience.

1.5 Relevance of this Research

Scientific relevance

Supply chain management and urban mining are two distinct disciplines. Both of which are to some extend moving in the direction of circular economy. Urban mining is inherently about the existing building stock. Supply chain management is often occupied with the circularity of newly constructed buildings. This research contributes to the body of work bridging the gap between disciplines.

The smaller deposit sizes mean that coordination with the demand side is essential to make sure that there are enough secondary materials available for a certain project.

Practical relevance

Policy makers have been attempting to stimulate the development of a circular economy in the construction sector (Schut et al., 2016). Reuse of reclaimed building components could play a big role in realising a circular construction industry. A study that identifies the drivers, barriers, and opportunities for component reuse is relevant for future policy measures.

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Theoretical Framework

Part I - A Circular Economy

This chapter attempts to give a comprehensive description of the current state of the art with regards to research concerning circular economy (section 2.1.1) and urban mining (section 2.1.2)

2.1.1 Circular Economy

Circular economy (CE) has seen a surge in popularity in recent years. One cannot do a literature study about CE without immediately running into the famous definition by the Ellen MacArthur Foundation: 'Imagine an economy in which today's goods are tomorrow's resources, forming a virtuous cycle that fosters prosperity in a world of finite resources.' (MacArthur, 2013). While this report brought CE under the attention of the general public, research on the subject has much deeper roots. In his publication Spaceship earth, Boulding (1966) makes the distinction between an 'open economy' with unlimited input resources and output sinks and a 'closed economy', in which resources and sinks are bounded and remain forever a part of the concerns of the economy (Boulding, 1966). He compares the earth to a spaceship where the crew will have to live the entire trip from the supplies they brought along. The earth is a lot bigger than a spaceship, but the analogy still holds. The resources buried in the crust of the earth and the ones that have been dug up since the industrial revolution are all there is. This makes circular ecol-

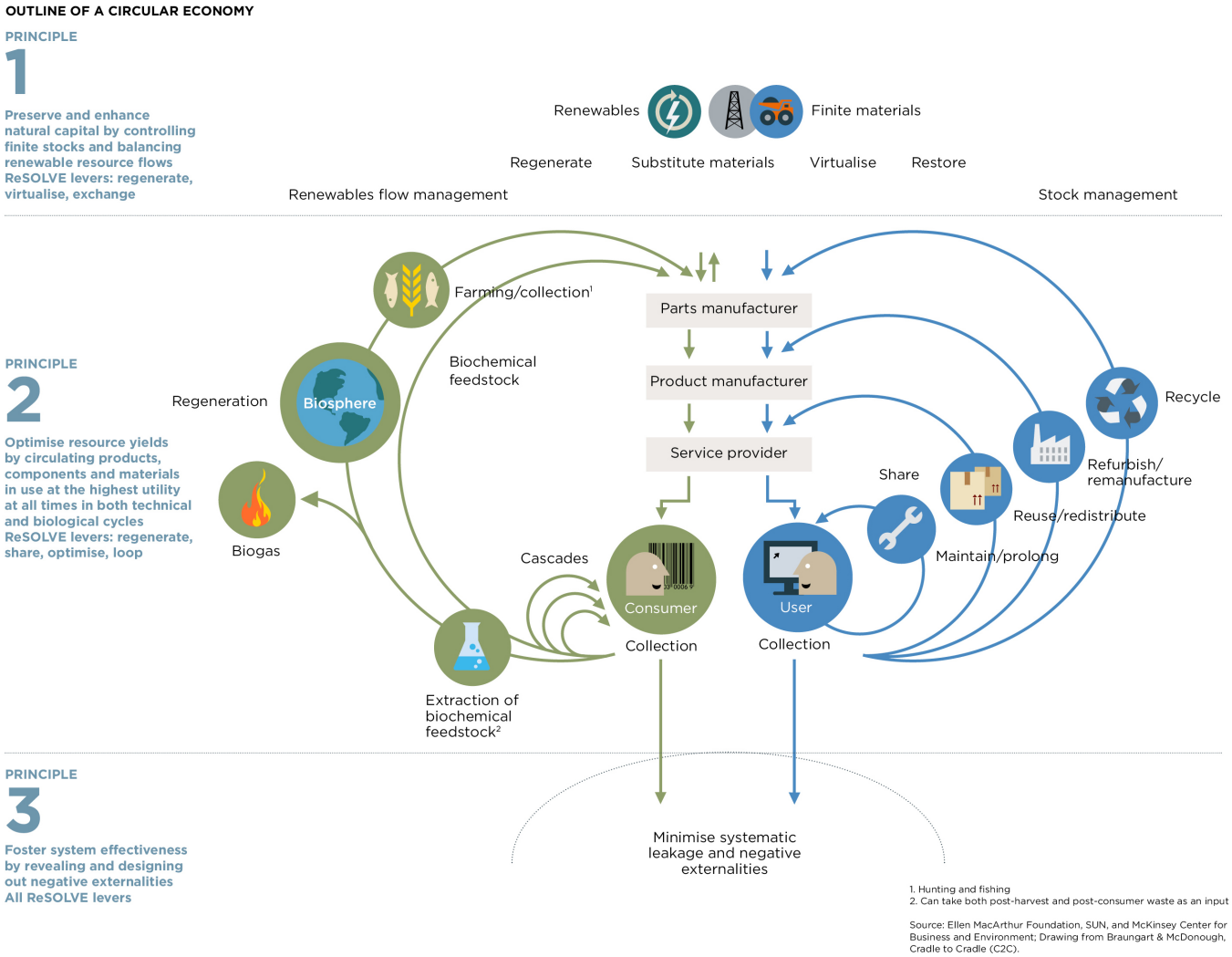


Figure 2.1 Circular economy by Ellen MacArthur (MacArthur, 2013)

ogy not so much a question of sustainability, after all for that there are more factors to take into account than just circularity, but a question of how to maintain our current standard of living without depleting our material stocks. According to Allwood (2014) 'The dogma of today's pro-environmental discussions in politics and mass media reporting assumes that aspiring to a 'circular economy' is one of the key technical fixes that will solve our environmental problems and allow the economy to keep on growing.' The European union argues however that the transition is a promising pathway to regional prosperity, enabling the 're-industrialisation of the European economy on the basis of resource-efficient growth that will last' (Hobson, 2016).

Defining Circular Economy for this Study

The concept of circular economy given by the Ellen MacArthur Foundation needs to be properly defined to be used in a scientific context. A working definition needs to cover the full meaning of circular economy and provide a basis to determine the circularity of a flow. Although there is no commonly accepted definition of CE so far, the core of CE is the circular (closed) flow of materials and the use of raw materials and energy through multiple phases (Z. Yuan, Bi, & Moriguichi, 2006). To arrive at the core of what CE is, we can first look at the two words that make up the concept: circular and economy. Economy is, according to the Oxford dictionary, 'the state of a country or region in terms of the production and consumption of goods and services and the supply of money.' Circular, in the context of movement, means: 'starting and finishing at the same place and often following roughly the circumference of an imaginary circle.' Since circular economy is about flows, rather than physical movement, following the circumference of an imaginary circle does not hold relevance here, the first part of the definition, how- ever, provides us with a good handhold to construct a definition of circular economy. Hobson (2016) uses the following definition: '[circular economy is] an industrial system that is restorative or regenerative by intention and design. It replaces the end-of-life concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse and return to the biosphere, and aims for the elimination of waste through the superior design of materials, products, systems and business models.' based on these references CE can be defined as: a system in which the resources used to provide goods and services do not have an end-of-life, but continue to flow through the system in multiple cycles without degradation.

Defining Recycling for this Study

To determine if an application can be considered circular it is not enough for something to be recycled, in a circular economy after all, resource flows should keep circling. Resources should be multi-cyclic. To form a good measure of an application's circularity the concepts McDonough & Braungart (2002) introduced the concept of up-cycling and the opposing concept of down-cycling. Where up-cycling means recycling without loss of quality and down-cycling is recycling resources into things that cannot be recycled again. In other words, down-cycling is just a delay of the end-of-life of a resource, whereas up-cycling is a step in the cycle of a circular economy (McDonough & Braungart, 2002). In my view, the term upcycling was poorly chosen as it suggests that resources have to be improved or gain in quality, therefore the term of choice is closed-loop recycling (Iacovidou & Purnell, 2016), suggesting a reintroduction in the cycle without loss or gain of quality. Products can only be truly circular if they are fully recyclable, as opposed to open-loop recycling. Products are circular if they can be produced from secondary or renewable resources and can mined as secondary resources in which the possible applications of these secondary resources equal those of the primary resources.

2.1.2 Urban Mining

Urban mining is an umbrella term for different recycling strategies aimed to recover materials from the built environment (Wallsten, Carlsson, Frändegård, Krook, & Svanström, 2013). It can focus on hibernating urban infrastructures, buildings that are being demolished or renovated, or simply all minerals available in cities from road dust to consumer goods. The PUMA project (Van Bueren, 2015) looks into metals present in buildings, regardless of demolition plans, working instead with an expected lifespan of the buildings. This means the focus of the research lies on prospecting, rather than mining.

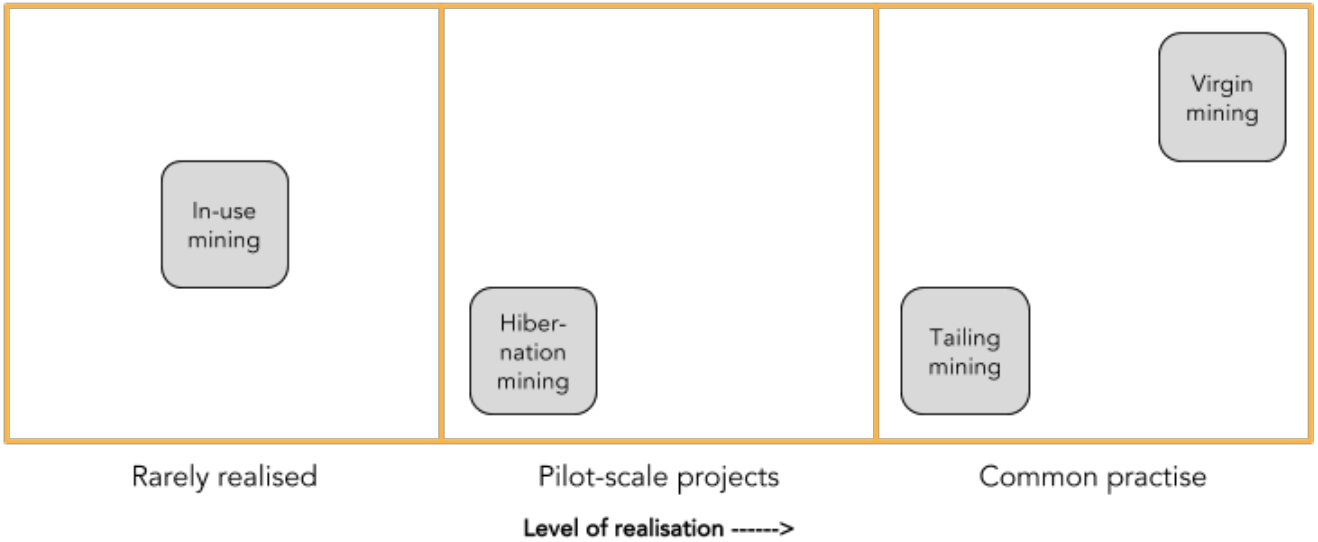
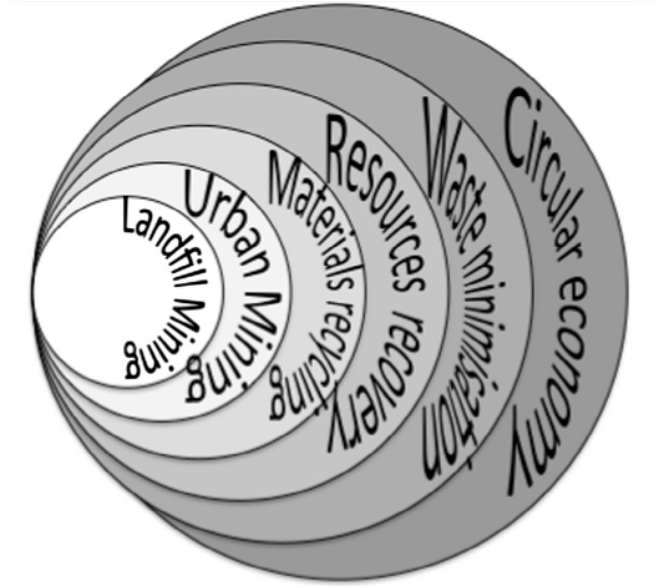


Figure 2.2: Types of mining and their frequency (adapted from Johansson, Krook, Eklund, & Berglund (2013))



Urban mining, a practical concept which is embedded within the framework of Circular Economy strategy has therefore arise as a way to systematically manage anthropogenic stocks that have been accumulating in the urban environment (Cossu, 2013; Cossu & Williams, 2015).

In order to realise the potential of urban mining some issues will need to be resolved. As a starting point, information is required on the quantity and quality of these metals, as well as on the time frame in which the metals will become available. One of the reasons that the potential of urban mining has so far been largely overlooked is a lack of knowledge regarding the actual occurrence urban resource stocks (Kapur & Graedel, 2006). To know when, and to what extent the urban metals can provide for future demand an exploration is needed. 'Like the geological survey of potential mines by mining companies, the urban mine will have to be prospected as to viability and value. In order to evaluate the potential for mining any kind of resource reservoir, information about its size, concentration, and location is fundamental.' (Krook, Eklund, Carlsson, Frändegård, & Svensson, 2010).

Figure 2.3: Sequential differences that refer to extraction of resources from waste (Cossu & Williams, 2015))

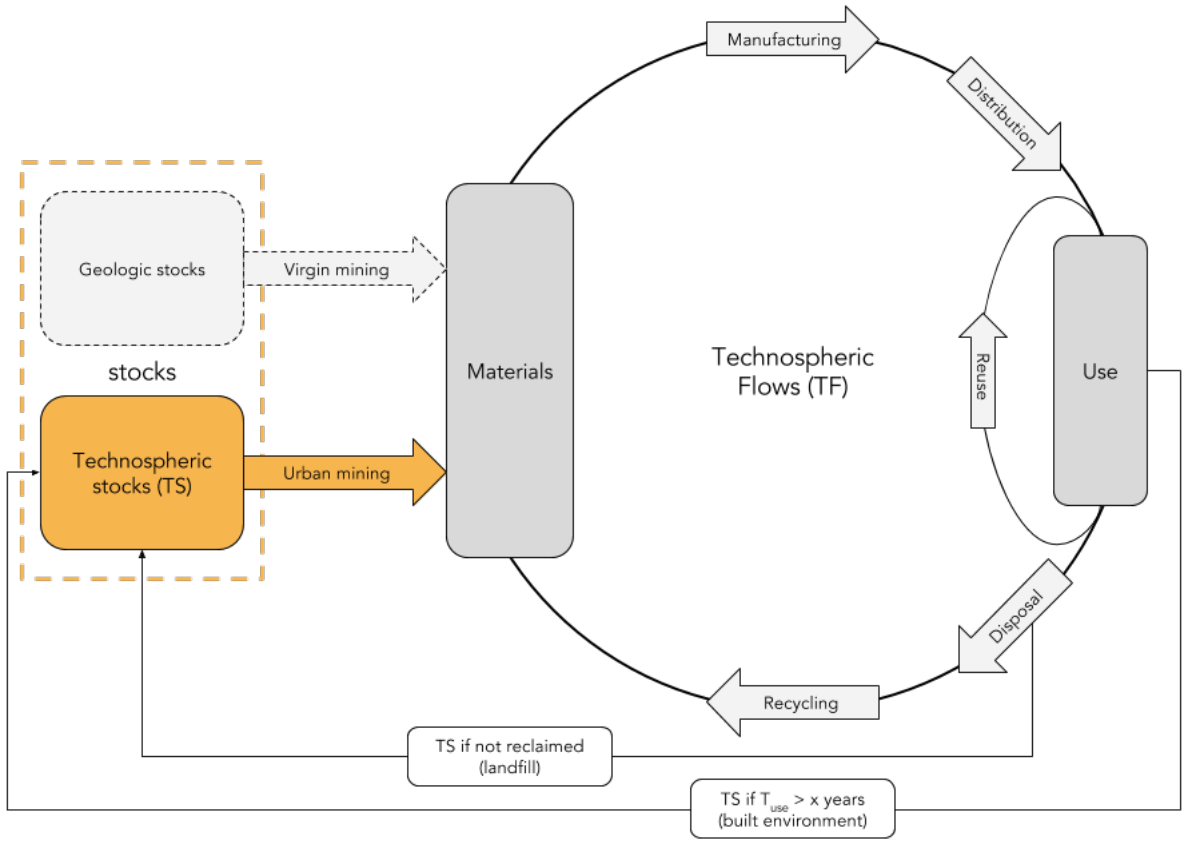


Figure 2.4: Technospheric stocks and flows - the place of urban mining in a circular economy

Defining Urban Mining for this Study

According to Brunner (2011), a general definition for urban mining has yet to be defined. He notes that: 'Whereas some researchers use the term to describe exploitation of resources from landfills, others apply it to traditional recycling schemes of waste materials, such as construction debris, scrap iron, plastics, or glass.' Krook & Baas (2013) makes a similar observation about the broad use of the term of urban mining and offers a narrower understanding: 'urban' means the area inside city borders and 'mining' is understood as the extraction of secondary metal resources from obsolete, and in that sense accessible, reservoirs situated in these areas.' Krook's understanding of urban mining is workable in his research into the mining of hibernating infrastructure, but lacks a generalisation needed in a universal definition. Lederer, Kleemann, Ossberger, Rechberger, & Fellner (2016) offer valuable input by noting that for technospheric resources a distinction can be made by their residence time in the technosphere as technospheric flows (e.g., waste streams) and technospheric stocks (e.g., landfills and built environment) (Lederer et al., 2016). The classification of being an anthropogenic stock resource, makes the mining metaphor more meaningful (Lederer et al., 2016) and the distinction between technospheric flows and technospheric stocks allows for a different understanding of the where to place urban mining in a circular economy. In a circular economy that is based on technospheric flows, urban mining can be used to tap into a stock of resources that was not originally part of the circular economy (figure 3.3). For this study, urban mining can be defined as: the mining of technospheric stocks in an urban environment; urban technospheric stocks mainly consist of buildings and infrastructure.

2.2 Circular Economy in the Construction Industry

Circular economy is gaining name among professionals working in the construction industry, but despite an industry wide awareness, applications have mainly been occupied with waste minimisation and recycling (Adams et al., 2017). Similarly, studies dealing with circular economy in the construction industry mainly deal with construction and demolition waste (H. Yuan & Shen, 2011), or focus on future circularity by means of 'Design for Deconstruction' (DfD) (Adams et al., 2017; Akinade et al., 2017). Designing with reclaimed components has so far failed to become mainstream and is mainly used in heritage projects (Gorgolewski, 2008). Pomponi & Moncaster (2016) developed a theoretical framework for research into circular economy in the construction industry. The framework will be described in detail in chapter 4.2.

2.1.2 Current Recycling Practises

The recycling rate of construction and demolition waste in the Benelux is close to 100% (A. R. Chini, 2005). However, recycling rate is not the only relevant measure to evaluate circularity. Most of the recycled materials end up in low value open-loop uses, rather than high value closed-loop ones. The rise of regulations that stimulate recycling have at a European level led to downcycling (Adams et al., 2017).

2.1.3 Current Reuse Practises

Before the industrial revolution component reuse was a completely ordinary thing. But even in more recent times reuse of components sourced from buildings was significantly more common than in our current day. Between 1997 and 2007 reclamation of components has decreased by 25% (Kay & Essex, 2009). The decline of reuse in favour of recycling means that many opportunities for reclamation do not get utilised and the chances for energy savings are missed. Circular awareness has led to the rise of new initiatives attempting to revive component reuse, but these initiatives have not found their way to become mainstream yet ('About – Rotor Deconstruction', n.d.; 'Gebruikte bouwmaterialen - Dé circulaire online bouwmarkt - Gebruiktebouwmaterialen.com', n.d.; Adams et al., 2017).

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Part II - A Supply Chain for Secondary Components

Finding the current drivers, opportunities, and barriers for component reuse in new buildings is a task that requires prior knowledge on a number of subjects. The goal of this chapter is to establish the theoretical framework for this study. Reuse of building components is a challenge with many facets that all warrant to be studied. In this study, the question is approached from the perspective of a project manager, and therefore puts the focus on organisational aspects of the question. While questions concerning e.g. structural integrity, safety, and health should not be dismissed and will come up in relation to organisational issues, they are not the focus of this study.

This chapter first deals with the topic of procurement in section 4.1; then continues to discuss current supply chain management practices in section 4.2; and concludes with an overview of current demolition practices in section 4.3.

3.1 Supply Chain Management in the Construction Industry

A supply chain is the chain of actors that handle a material from cradle to grave. whether or not there is any collaboration between those actors does not matter. Formally, a supply chain is an integrated process wherein raw materials are manufactured into final products, then delivered to customers (Beamon, 1999). A typical supply chain is depicted in Figure 3.1.

The construction industry differs from other industries in many ways. Buildings are usually one-off projects build by a temporary organisation on

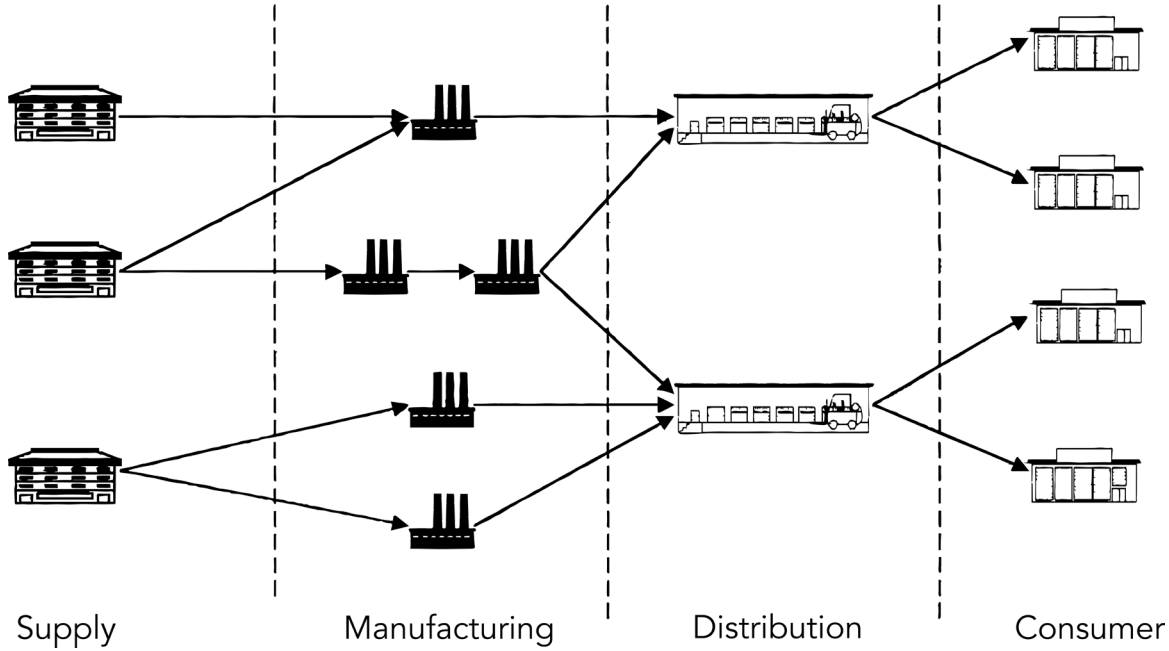

Figure 3.1: Linear supply chain (Beamon, 1999).

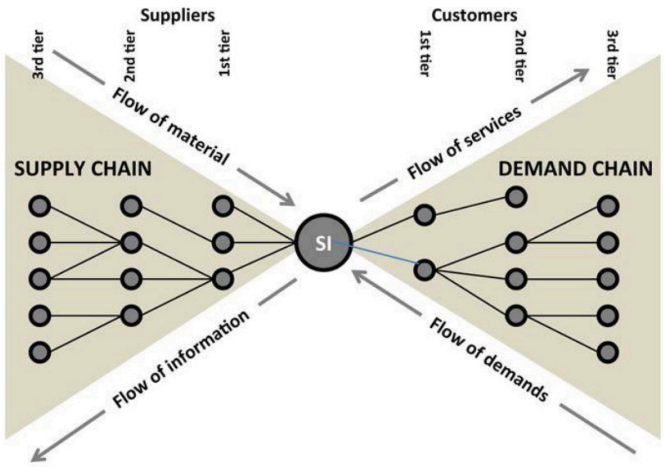

Figure 3.2: Convergence of the supply chain in the construction industry (Segerstedt & Olofsson, 2010).

a made-to-order basis (Segerstedt & Olofsson, 2010). Furthermore, construction supply chains are convergent towards a single product, the building, rather than producing multiple products going to multiple customers (Vrijhoef & Koskela, 2000).

Communication and integration between different actors in a supply chain is universally seen as important in Supply chain management, although the reasons for this integration can differ. Alonso, Gregory, Field, & Kirchain (2007), draw the conclusion that supply chain integration is important based on the argument of material scarcity. They state that 'It is critical that all stakeholders become aware of the potential impact of raw material supplies on their business. If those raw materials be-

come difficult to acquire, market forces may shift demand to other goods and therefore other supply chains.' (Alonso et al., 2007). It is important to notice that the material scarcity she mentions comes from an economic viewpoint as opposed to the environmental viewpoint that is often taken. This is not the case in typical construction supply chains, where the stakeholders that set the demands are usually not directly involved in procuring the required materials (Vrijhoef & Koskela, 2000).

According to Vrijhoef & Koskela (2000), supply chain management can fulfil four roles in the construction industry, these roles are: [1] improving the interface between site activities and the supply chain; [2] improving the supply chain; [3] transferring activities from the site to the supply chain; and [4] integration of site and supply chain.

closed-loop supply chains

Theory on closed loop supply chains for diverse product classes has been widely published. With regards to the construction industry however, research into closed loop supply chains has thus far been minimal. According to Schultmann & Sunke (2006), closed-loop supply chains do not yet exist in the construction industry. The need for recovering valuable materials from the urban environment after their end of life has been discussed extensively. According to Alshammari & Ball (2016), closed loop supply chains are a core process for recovery of those materials. According to Guide, Harrison, & Van Wassenhove (2003) a reverse supply chain requires careful design, planning, and control. Like most existing literature the focus unfortunately lies on single-actor closed loop supply chains, but that does not render his claim invalid.

3.1.2 Procurement in the construction industry

Procurement in the construction industry is often done by means of a call for tender. In the EU public companies are required to use this method (Chao-Duivis, Koning, & Ubink, 2008), but in order to get the best deal private companies will often use some form of tendering as well.

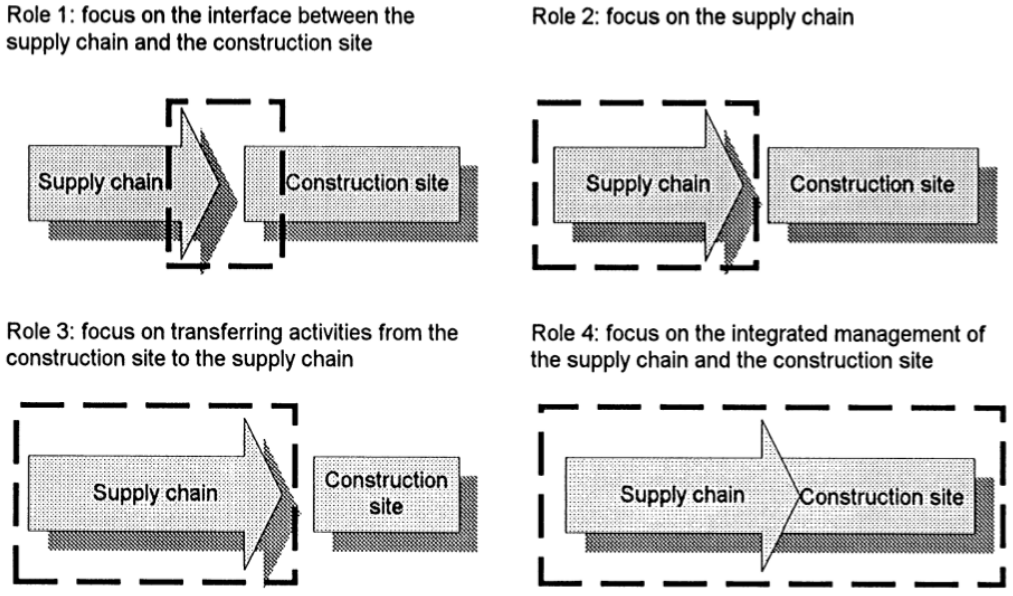

Figure 3.3: integrated supply chains (Vrijhoef, 2011)

3.2 Current Demolition and Recycling Practices

This chapter delves into the current state of affairs in the building industry. Matters such as current recycling practises, initiatives like material passports and markets for secondary materials are discussed.

3.2.1 High value recycling and reuse

More than 90% of the CDW generated in the Netherlands, measured by weight, is being recycled (Kristinsson, Hendricks, Kowalczyk, & te Dorsthorst, 2001). Whilst this number suggests a successful adaptation of circular economy principles in the construction industry, most of this material is used as foundations for roads. This means that, while by some definitions this counts as recycling, it is still a few steps away from the material loops envisioned in a circular economy. The Ellen MacArthur foundation has defined several loops that make up a circular economy, of which recycling is the outermost loop (MacArthur, 2013). However, as discussed before (section 2.1.1) this study makes a distinction between open-loop recycling and closed-loop recycling. By this definition, recycling as foundation for a road is considered open-loop recycling since reclamation for a third loop has become infeasible.

Even though recycling takes place on a big scale within the Dutch construction industry a circular construction industry is far off. As defined in section 2.1.1, a circular economy requires materials to have multiple cycles of reuse. CDW used as foundation for a road cannot be reclaimed for use in a building, therefore while up to 90% of CDW in the Netherlands is recycled, a circular construction industry is still far off.

Why reuse?

According to Iacovidou & Purnell (2016), the environmental benefits of recycling cannot be generalised as these can vary widely from one material to another. While open-loop recycling has become mainstream for CDW more value can be maintained when materials are used at a higher level. This is represented by the loops of the circular economy diagram (fig. 2.1, p.17), but has been described more explicitly in the Delft Ladder (Table 3.1). The production of components requires resources such as raw material and energy. Energy used for the production of a component is lost when that component is recycled on a material level. However, in the case of reuse the embodied energy of components is not lost. While components may require some minimal remanufacturing, the energy requirements for this are much lower than those for recycling (Iacovidou & Purnell, 2016).

1	Prevention	Extending use
2	Reuse of constructions	Reuse
3	Reuse of building elements	
4	Reuse of materials	
5	Useful application as residue	Recycling
6	Immobilisation with useful application	
7	Immobilisation without useful application	
8	Incineration with energy generation	Waste
9	Incineration	
10	Dumping	

Table 3.1: Delft Ladder (adapted from Hendriks & Janssen, 2003)

3.3 Circular Demolition for Component Reuse

The reclamation and reuse of components from the current building stock rests on four aspects: technical, environmental, economic, and regulations (Kristinsson et al., 2001). According to Gorgolewski (2008), however, the impediments to reuse are seldom technical or economic. Instead plans to integrate reclaimed components into new buildings experience difficulties in various organisational aspects.

3.3.1 Procurement for reuse

As discussed in section 4.1.1 there are many procedures for procurement in the construction industry and is no such thing as a 'standard' procurement method. However, there are elements that are shared by the most used procurement methods. Procurement practises for buildings that incorporate reuse differ in one important way. "In normal building the design team first designs the structure up to scheme or detailed design and then suitable goods and materials are sourced and purchased. In a reuse building, it will often be necessary to source and purchase the goods and materials before the design has reached the detailed design stage" (Addis, 2012). "Deconstruction is the careful dismantling of a building or structure to maximise the recovery of its components for reuse." (Iacovidou & Purnell, 2016). A comprehensive overview of the state of deconstruction and component reuse in various countries was published in 2005 (A. R. Chini, 2005). While a lot of changes can have taken place since then, the challenges faced back then are valuable input for determining the current drivers, barriers, and opportunities. Chini & Bruening (2003) composed a list of the challenges faced by deconstruction in the United states:

- existing buildings have not been designed for dismantling;
- building components have not been designed for disassembly;
- tools for deconstructing existing buildings often do not exist;
- disposal costs for demolition waste are frequently low;
- dismantling of buildings requires additional time;
- building codes and materials standards often do not address the reuse of building components;
- unknown cost factors in the deconstruction process;
- lack of a broad industry identity with commensurate standardized practices;
- buildings built before the mid-1970's with lead-based paint and asbestos containing materials; and the economic and environmental benefits that are not well-established.

Some of these challenges can be, and have been, easily overcome. Other challenges proved to be of a more difficult nature. While some of the aforementioned challenges touch upon challenges within the bigger supply chain, most of them are practical challenges.

When is reuse meaningful?

This study takes an approach to circular demolition that emphasizes component reuse over recycling. This approach was chosen based on the waste hierarchy (Hendriks & Janssen, 2003), that was developed to find a new use for materials while minimising losses of value. It was found that, since component reuse in the construction industry is barely happening (Kay & Essex, 2009), this is a step in the hierarchy where a lot of improvement is possible. Nonetheless it is important not to lose sight in the process by finding ways to reuse components that could have better applications.

When does it make sense to reuse components? Are there cases in which alternatives would make more sense? Starting with the cases of Bouwcarrousel and Rotor DC it can be noted that both companies share the opinion that there are materials for which recycling makes more sense than reuse. The ambitions of these companies with regards to component reuse differ significantly though. Rotor DC aims to eventually reclaim 5% of a building's components for reuse, whereas Bouwcarrousel aimed to reclaim everything that could be reused for reuse, which by their estimate came down to about one third of the building. In many cases high quality recycling could be preferred over reuse. However, currently there are still gains to be made in component reuse as proven by the fact that circular demolition company only reclaim a fraction of the components that could technically be recovered (L. DeVlieger, personal communication, October 2, 2017), and different circular demolition companies succeed in finding demand for different components (B. Albers, personal communication, November 17, 2018).

Methodology

This research has an exploratory objective and therefore requires a research method that maximises exploration possibilities. A holistic and qualitative approach is taken to answer the research question (Kumar & Phrommathed, 2005).

4.1 Study Design

The research question: "How can components reclaimed from the current building stock be reintroduced into supply chains in the construction sector?" is answered in three parts by means of three secondary research questions.

1. What can current cases reveal about the drivers and barriers of reclaiming building components from existing buildings?
2. What can current cases reveal about the drivers and barriers of integrating reclaimed components into new buildings?
3. Which opportunities for component reuse can be found in current cases?

The conceptual model (figure 4.1) shows the most important steps of the research. Before empirical research can be conducted, boundaries need to be established. Literature research will be used to establish the current state of circular economy in the construction industry and develop criteria for the cases to include. The remaining research questions will be answered by means of a multiple case study.

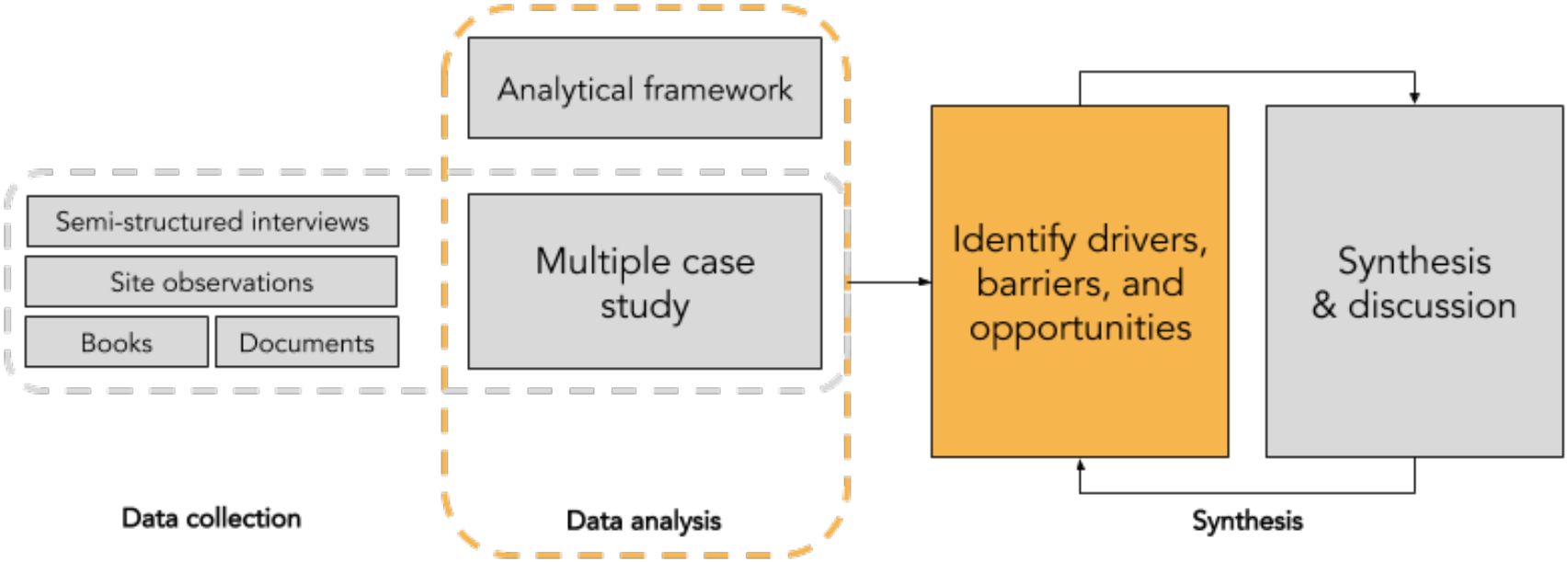

Figure 4.1: Conceptual model of the research.

4.2 Research Strategy

The primary research strategy of this study is a multiple case study research. The selected cases share a common characteristic that is of interest to this study. According to Stake (2006) multiple case research starts with a phenomenon that needs to be studied, in this case the reuse of building components. Single cases are of value to better understand this phenomenon, but the essence is to study the similarities and differences between the cases to gain a better understanding of component reuse in the construction industry (Robert E. Stake, 2006). Case studies allow for the in-depth investigation of component reuse in the 'real world' rather than being limited to prior research, it is therefore considered a fitting method for answering the research questions posed above. The cases are selected on their relevance on the details of setting up a supply chain that includes reuse of building components. This makes the cases instrumental, rather than intrinsic, their function lies in exploring, describing or explaining a certain issue or phenomenon, rather than being the main subject of research by themselves (R. E. Stake, 2006). The individual cases "explore a bounded system (...) through detailed, in depth data collection involving multiple sources of information (...) and reports a case description and case-based themes" (Creswell, 2009).

After the data collection the individual cases are described and analysed, followed by a cross case analysis. For this analysis, a framework has been selected to ensure a complete and objective analysis of the identified drivers, barriers, and opportunities. Pomponi & Moncaster (2016) propose a framework that can be used to aid research into circular economy in the built environment. A key component of this framework is the inclusion of societal and behavioural elements, which are often omitted in favour of technical elements.

The framework used for the analysis of the cases consists of six dimensions that cover different disciplines (figure 2.2). The multi-disciplinary approach of the framework ensures that the cases are analysed from all angles that are relevant to circular building and makes it perfectly suitable for the analysis of the drivers, barriers, and opportunities present in this multiple case study. "The peripheral arrowed arcs represent the need for a holistic approach and a harmonised collaboration of research initiatives in each of the six pillars. Second, the inner dashed lines stress the importance of practical links between each pillar and the others."

The six dimensions were chosen by Pomponi & Moncaster (2016) based on a literature review. While they give a comprehensive overview of the studies that the dimensions were based on, a definition of the individual dimensions is absent from their paper. In addition to the analysis based on the six dimensions explained above, an attempt will be made to find measures to lift identified barriers and utilise the opportunities. In order to do this, elements from policy analysis (Enserink et al., 2010) , will be used in in tandem with the framework of Pomponi & Moncaster (2016).

Even though the six-dimension framework was developed specifically for research into circular economy in the built environment some changes are needed to make it fit the cases of this study. The authors themselves note that, while all six dimensions are important, not all six of them may be equally relevant for every study, in section 4.3 of this research each of the dimensions is elaborated and its relevance evaluated.

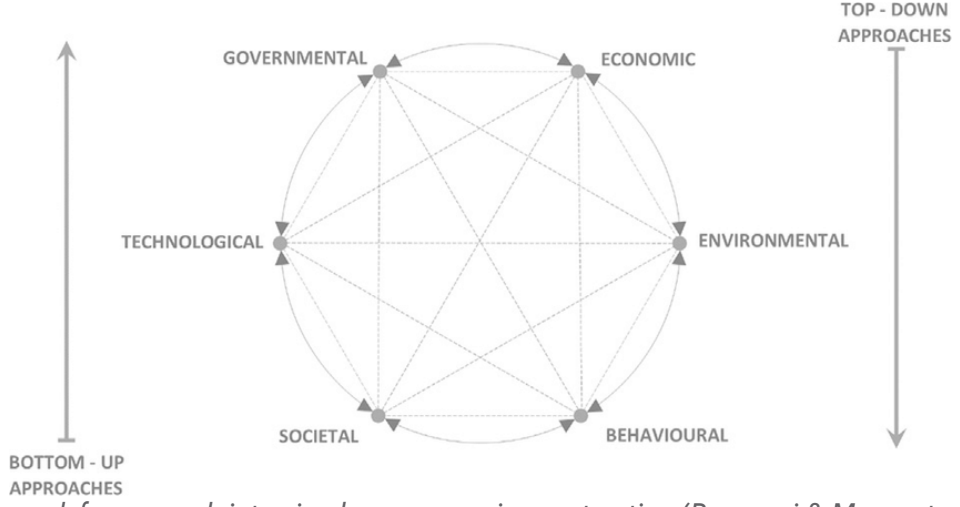

Figure 4.2: Framework for research into circular economy in construction (Pomponi & Moncaster, 2016).

4.2.1 Quality of the research

The quality of the quantitative research is ensured in terms of validity, reliability, and generalisability.

Limitations of the research

This research is conducted as graduation project for the master track Management in the Built Environment at Delft University of Technology. Therefore, the research is conducted within a limited amount of time, with a limited budget and within the geographical scope of the Benelux.

4.3 Analytical Framework

Whereas the framework by Pomponi & Moncaster (2016) was developed to analyse a circular economy in the built environment on a macro-level, this study is focussed on products used in the construction industry on a micro-level . The six dimensions of the framework remain relevant for this study, but while it is true that they can all influence each other, for the purpose of this study focussed on which drivers and barriers influence component reuse a different perspective is more useful. By taking economics as a starting point the supply chain of reused components becomes the centre of the framework. This places supply opposite of demand within the economic dimension. Without outside factors to influence the supply and demand they are expected to balance each other out due to regular workings of the economy. The remaining five dimensions established in the six-dimensional framework are acting on the economic dimension. Factors from each dimension can act in a stimulating manner, thereby becoming drivers, or in an obstructing manner, becoming barriers.

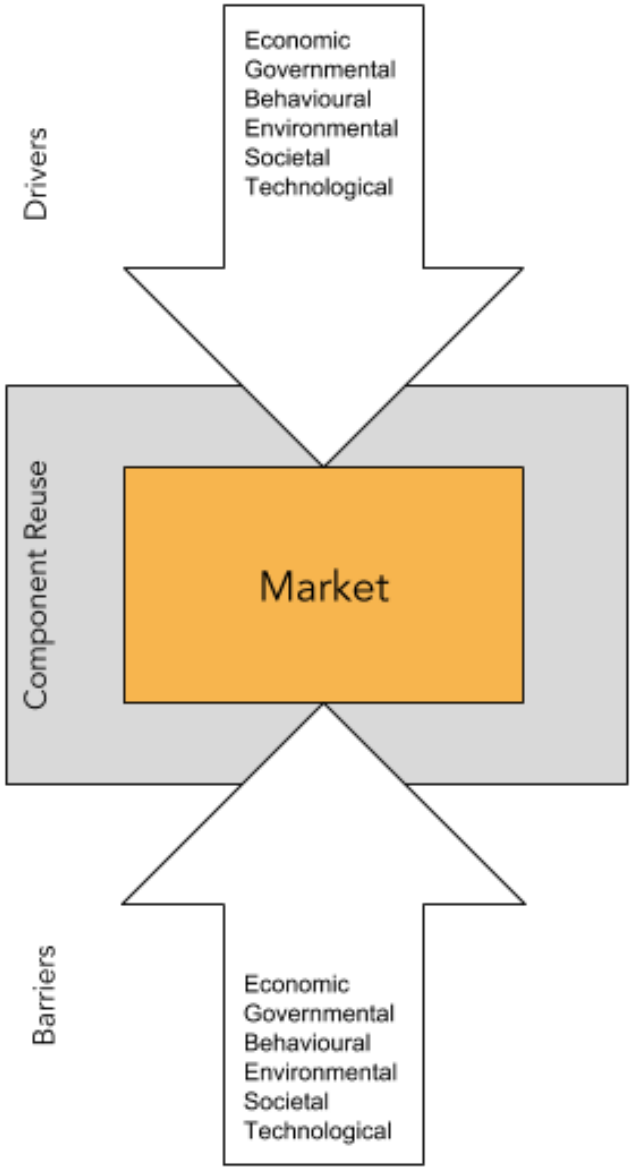

Figure 4.3 Analytical Framework

Building blocks of the analytical framework

Block 1 – Drivers and Barriers

This study is set at the intersection of urban mining theory and practical business models. The cases included in this study consist of real world attempts at component reuse in the construction industry. In the development of business models as well as in de day to day of running their business the actors are trying to exploit business opportunities. In the field of business models for renewable energy studies often show an interest in the identification of business opportunities for renewable energy systems (Chesbrough, 2010). Researchers analysing organisational changes consider drivers and barriers influencing factors on a (successful) business model (Argyris, 1993; Guenther, Scheibe, & Farkavcová, 2010). The fields of research into renewable energy and urban mining are both part of research into circular economy making this approach relevant for this study.

Engelken, Römer, et. al. (2016) identified drivers, barriers, and opportunities in a structured manner by analysing a number of papers selected for a structured literature review. Digging deeper in the papers they analysed it becomes clear that there are a number of ways by which to identify drivers and barriers, but the methods are rarely formalised. The identification of opportunities is a different matter altogether and is by definition not exhaustive.

The scope of this research are the current drivers, barriers, and opportunities for component reuse in the Benelux, therefore the relevant cannot be acquired from research conducted in other countries at another time. Case studies are

the most suitable method for acquiring the necessary information. Walker, Di Sisto, & McBain, (2008) utilise both a literature review and interviews for the identification of drivers and barriers. In the interviews the drivers are identified by asking for them both directly and indirectly. This method is used in the interviews that are part of the multiple case study of this research as well.

Asking for drivers and barriers directly is an effective way to identify drivers and barriers that can be compared between cases (Appendix A – Interview Questions). The answers given by an interviewee taken on its own, however, cannot be taken as fact as it is not possible to distinguish e.g. real barriers from perceived barriers (Dunant et al., 2017).

Block 2 - Supply chain framework

In a traditional setup of the supply chain in the construction industry, both information flow and material flow are one directional in opposite directions (Vrijhoef & Koskela, 2000). This poses problems for the integration of reclaimed components because this requires information about the components to be passed through to the designers.

Block 3 - Six dimensions framework

The research does not stop after merely identifying the drivers and barriers within the cases. To allow for a comprehensive analysis and the identification of emergent opportunities, the identified drivers and barriers need to be organised in a framework. This can be approached in several manners. Engelken et al. (2016) use a structure of internal drivers and barriers in combination with a distinction between

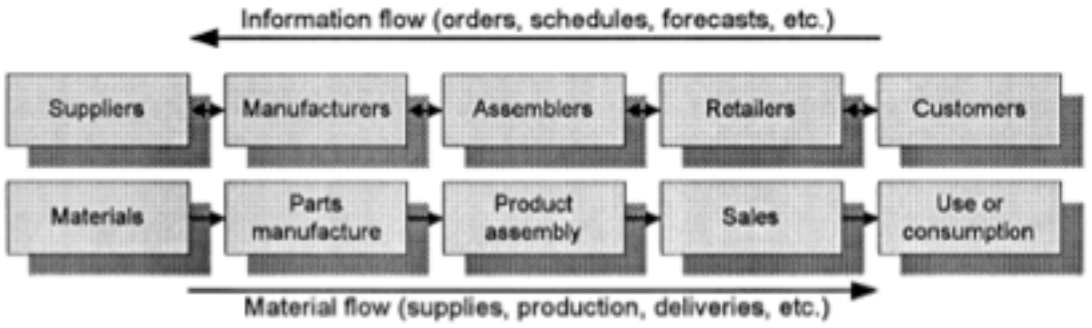

Figure 4.4: The flow of information and materials in a traditional supply chain (Vrijhoef & Koskela, 2000).

developed and developing countries. A similar approach is taken by Walker et al. (2008), but as secondary classification the drivers and barriers were grouped together in sensible categories. These categories were based on the already identified drivers and barriers that could then be analysed further.

Establishing categories based on the results can lead to valuable insights. However, for this research predefined categories will be more appropriate to ensure the compatibility with research into urban mining. The Theoretical Framework for Circular Economy Research in the Built Environment discussed in section 2.2 (Pomponi & Moncaster, 2016) provides those categories. This framework consists of six dimensions based on literature. While Pomponi & Moncaster (2016) give a comprehensive overview of the studies that the dimensions were based on, a definition of the individual dimensions is absent from their paper. The dimensions are listed below accompanied by a short definition:

- Governmental dimension

The governmental dimension covers everything that is related to government.

- Economic dimension

The economic dimension covers all financial aspects of a business.

- Environmental dimension

Environmental encompasses everything that includes the protection of the natural world.

- Behavioural dimension

The behavioural dimension includes everything related to the behaviour (including perceptions) of companies or individuals.

- Societal dimension

Not to be confused with the behavioural dimension, the societal dimension addresses more systematic societal factors.

- Technological dimension

The technological dimension includes everything relating to or using technology.

The focus of this particular study on component reuse in practice (micro-level) would seem to make

the dimensions with a focus on the macro-level less relevant. But while the governmental dimension is a macro-level dimension, its effects go down all the way to the micro-level. Another example of this is the environmental pillar. While the environmental drivers are often voiced at a macro-level, this is still a useful dimension to identify drivers and barriers as personal motivation of leaders in small businesses could be quite a significant factor. Therefore, all six dimensions will be considered in the analytical framework of this study.

4.4 Case Selection

Case study research is not based on a random sample, rather a case that is typical for the phenomenon to be researched should be selected. This case should be able to provide as much information as possible and the researcher attempts to understand the case in its entirety by gathering information from all available sources (Kumar & Phrommathed, 2005). The explorative nature of this study lends itself better to a study of multiple cases because the selection of a single representative case would need a greater body of existing research.

The cases from which the most valuable information can be extracted have been selected using criterion-based, purposeful, and purposive sampling (Merriam & Merriam, 2009). This research comprises samples through multiple levels. Purposeful sampling 'involves locating a few key participants who easily meet the criteria established for participation in the study. As you interview these early key participants you ask each one to refer you to other participants.' (Merriam & Merriam, 2009). Individual cases should be approached as a fully standalone case study, in which sampling is approached accordingly (Corbin & Strauss, 1990). The number of cases included should range from four to fifteen (R. E. Stake, 2006) and they should present a logical inference about the phenomenon of interest (Bryman, 2012). Cases are included based on the following inclusion criteria for collective cases:

- The firms have past or current projects regarding deconstruction and/or component reuse;
- The firms vary in terms of components they focus on for reuse;
- The firms may vary in their approach on both reclaiming components and reusing components.

Within individual cases the sample will be a convenience sample. 'A convenience sample is one that is simply available to the researcher by virtue of its accessibility' (Bryman, 2012).

Four cases have been selected to be relevant for this study. The use of multiple methods for data collection is an important aspect of case study research (Kumar & Phrommathed, 2005). Therefore, data about these cases originates from multiple sources, including a minimum of one semi-structured expert interview per case, focus groups, and secondary literature. The interviewed experts are currently active in traditional construction projects and are or have been involved in pilot projects involving building with reused components or reclaiming components.

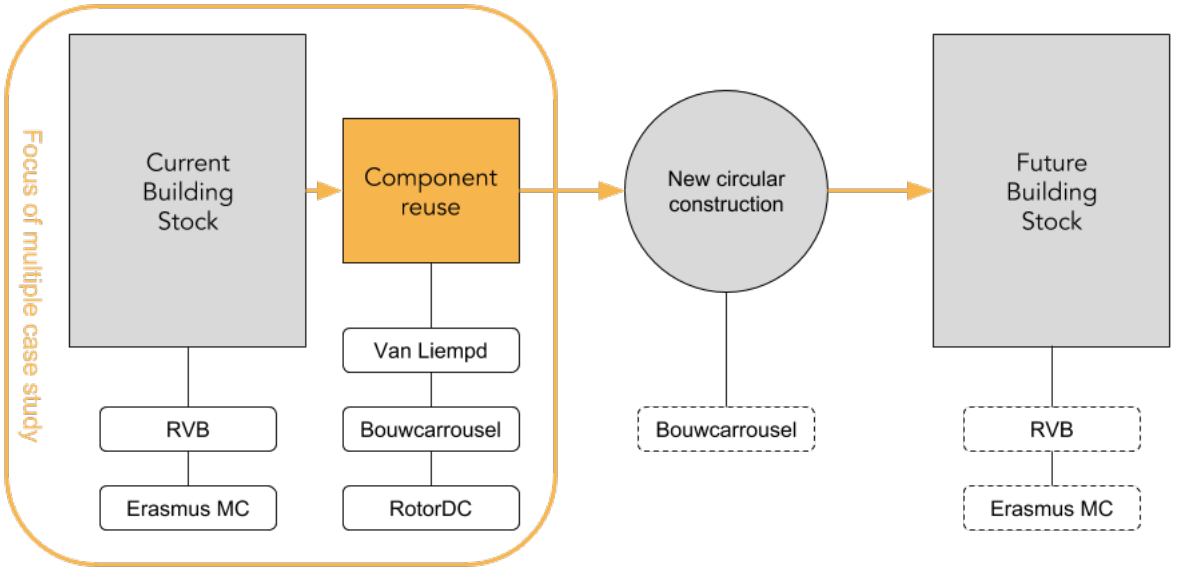

Figure 4.5: Cases and their location in the big picture

A series of informal interviews was conducted to establish the options for setting up circular supply chains in the construction sector:

- Circular demolition/deconstruction companies
- Collection and dissemination of information availability of materials
- Material Passports
- Pre-demolition audits
- Listing Services (like Craigslist)
- Circular buildings

To answer the research questions the selection of suitable cases is imperative. The case selection is based on the representativeness of the cases for the larger supply chain. At first eight cases have been selected to cover all places in the list above. Based on the focus of this research on the existing building stock as well as unstructured interviews were conducted with representatives from every case, after which a decision was made to limit the number of cases to two facilitating cases and two cases that are on the supply side, with possible demand for reclaimed components.

4.5 Operationalisation

The data collected in this research is meant to develop an in-depth understanding of the selected cases. Data consists of information from different sources including semi-structured interviews, site-visits, focus groups, and secondary written materials. Analysis and interpretation is carried out by coding and production of diagrams. Little research into circular economy in the construction sector has gone further than waste minimisation and recycling (Adams et al., 2017). To guide further research such as this study Pomponi & Moncaster (2016) have developed a framework that aims to help studies to include all dimensions relevant to circular economy in the built environment. These dimensions that have been discussed in section 4.2 form the basis for the analysis of the drivers, barriers, and opportunities that can be identified from the cases.

Step	Title	Objective(s)	Research method(s)
One	Literature review	Explanation of the concept	Literature review
		Discuss completeness of the concept	
Two	Selection of cases	Define the variables for selecting cases that are relevant for the research topic. Select cases that are able to provide a deeper understanding of component reuse its drivers and barriers	Brainstorm sessions
			Conference attendance
			Explorative interviews
Three	Case description and identification of drivers and barriers	Describe the cases	Literature research
			Semi-structured interviews
		Discuss the drivers and barriers encountered in the cases	Site observations
			Additional case data
Four	Analysis of drivers and barriers	Create an overview of the different drivers and barriers	Research framework
		Analyse the drivers and barriers and their interconnections	Draw interconnections
			Literature review
			Link to literature
Five	Synthesis of opportunities	Synthesis for entrepreneurs	Research framework
		Synthesis for policy makers	Policy analysis

Table 4.1: Operationalisation Scheme

Literature review

The literature review gives a comprehensive description of the state of the art with regards to research concerning circular economy, urban mining and supply chains in the construction industry. It serves as a foundation for the remainder of the study.

Selection of the cases

Based on the literature review the steps that are commonly taken to reuse building components are identified and used as a basis to select the cases.

Case description and identification of drivers, barriers, and opportunities

The cases are analysed on drivers, barriers, and opportunities (method based on Engelken, Römer, Drescher, Welpe, & Picot (2016)). Every influencing factor identified in the cases is classified as either stimulating or obstructing component reuse in the respective case. Opportunities can be both untapped, meaning that the net influence on the case is currently zero, or drivers or barriers that can be either lifted or enhanced.

Analysis of drivers and barriers

The analysis of the drivers and barriers that have been found in the previous step is aided by the use of the six dimensions that have been developed by Pomponi & Moncaster (2016). The drivers, barriers, and opportunities are placed in dimensions. Some drivers, barriers, or opportunities might fit in multiple dimensions and will be assigned as such. Grouping findings in appropriate categories helps to make connections and identify opportunities that might otherwise be missed. The analysis will be aided by the drawing of diagrams based on the analytical framework.

In their disquisition of the six dimensions Pomponi & Moncaster (2016) give adequate reasons for the relevancy of each individual dimension, but they refrain from providing a workable definition of the dimensions. To be able to apply the six dimensions within the analytical framework of this study further operationalisation is required. The definitions of the six dimensions used in this study can be found in table 4.2.

Operationalisation of the six dimensions

	Definition	Notes
Economic	justified in terms of profitability.	Profitability of one company No individuals.
Governmental	Any form of policy instated by a governing body to encourage or discourage component reuse.	The governing body can also be the board of a company. This does not include the government acting as a client.
Behavioural	Behaviour by individuals that is not caused by economic motives. Including individual behaviour with economic basis	Employees don't share in the profit of their company therefore drivers or barriers leading back to employees are considered to be behavioural.
Environmental	Drivers and barriers primarily based on the moral wish to minimise environmental impact.	Economic motives are usually secondary for this dimension This dimension is not about the but about the environment of the planet.
Societal	Relating to the current way that society works.	In this case current workings of the construction industry Acknowledge inertia in existing supply chains.
Technological	Any technology that can influence supply and demand of reclaimed components.	This can be facilitating technology or the lack of facilitating technology.

Table 4.2: Operationalisation of the Six Dimensions

Synthesis opportunities

The synthesis of opportunities follows from the framework established for the analysis of drivers and barriers. The findings are compared to the analytical framework and are visualised in the same manner.

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Findings

Part I - Analysing the Cases

In this chapter the four cases, selected by methods discussed in chapter 4, are first described and subsequently used in dialogue with the literature study to answer the research questions regarding drivers and barriers. The drivers and barriers for integrating reused components into new buildings have been identified by coding and analysing the array of data collected in the case study research described here.

5.1 Case descriptions

Four cases have been selected that are relevant for this study. Data about these cases originates from multiple sources, including site observations, unstructured interviews, a minimum of one semi-structured interview with an expert per case, focus groups, and secondary literature. The interviewed experts are currently active in traditional construction projects and are or have been involved in pilot projects involving building with reused components or reclaiming components.

There are multiple ways in which supply and demand of reclaimed components can be matched. The five cases have been selected to cover two of the possible options (fig. 5.1):

- Facilitator cases
- Customer cases

The facilitator cases focussing on inter-organisational reuse are about companies situating themselves as a middle-man between supply and demand. The customer cases cover two organisations that have buildings they want to have demolished in a circular way. They could be classified as intra-organisational since both supply and demand of reclaimed components exist within their own organisation. However, thus far there have been no cases where this match has been utilised.

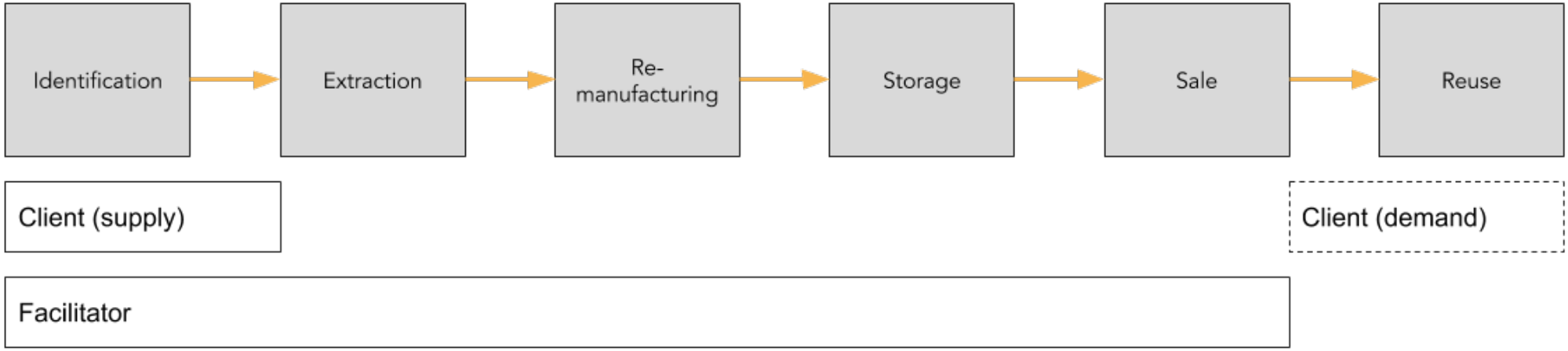

Figure 5.1: Context of cases in the supply chain.

5.1.1 Rotor DC

Figure 5.2: Depot of Rotor DC.

Rotor DC was started in 2012 by the architects Lionel DeVlieger and Maarten Gielen as an autonomous part of their existing non-profit firm Rotor. It is an autonomous side-project of Rotor, a Brussels-based non-profit firm engaged in promoting and facilitating the reuse of building components as a strategy on the path towards a more resource-efficient materials economy.

Through this study, we discovered that despite the increasing professionalization of the sector, many vendors are still focusing on rustic materials destined for the domestic (neo-)rural market. Few are geared towards selling what comes out of large building compounds of the service sector, which make up the bulk of demolition debris in metropolitan areas like the Brussels Region. Rotor Deconstruction grew out of the realization that certain dots needed urgent connection.

Rotor DC is a company that specialises in the reclamation, remanufacturing, and resale of used building materials and components. Their depot is located in an old chocolate factory in Brussels South. Their focus lies on high quality, mass produced materials and components. A unique aspect of the business model of Rotor DC is that they do not charge for their work, and in return do not get charged for the components they reclaim.

Business model

The business model of Rotor DC is based on their prior experience as architects that integrated reclaimed building components in their buildings.

Their team of approximately twenty people is divided over the two companies, Rotor for research and Rotor DC for the circular demolition. The team of Rotor DC contains experts in three services: architects that can judge building components in place on their value and reusability; contractors with experience in disassembly; and movers that can transport the reclaimed components to the customer or the depot.

Rotor DC's focus is on office buildings, usually in Brussels, but sometimes in other places in Belgium. If such a building is designated for demolition Rotor DC often gets invited to inspect the building for reclaimable components. This invitation is often extended by the building owner or one of the demolition companies in their existing network. Their incentive for inviting Rotor DC is generally partly economic and partly for environmental reasons. Companies frequently request an evaluation of the environmental impact of the operation (L. DeVlieger, personal communication, May 14, 2018). After an assessment of the components that can be reclaimed Rotor DC sends in their contractor to strip the building of the reusable components before the full demolition commences. Clients receive detailed reporting on salvaged materials and can use this information for sustainability assessments and public relations. Operations are run on a fixed budget and are zero-risk and zero-investment. ('Services – Rotor Deconstruction', n.d.).

In their original business model Rotor DC attempted to find buyers before or during the disassembly process, allowing them to transport reclaimed components directly to a new customer. Due to the difficult nature of matching supply and demand in this way, the model has shifted to favour transportation to their depot (L. DeVlieger, personal communication, October 2, 2017).

Since January 2017 Rotor added a consignment option to their services. With this service Rotor DC will assist in the assessment of components that are suitable for reuse. The difference with the original Rotor DC services is that disassembly and transport to the depot are for the costs of the demolition company. After delivery at the depot Rotor DC takes care of the sale, but the ownership stays with the demolition company. Proceeds are usually shared fifty-fifty.

Role in a Project

Rotor DC has people for making the inventory of a building, do the disassembly of valuable components, move those components to the customer or their depot, and subsequently sell the components. However, the main thing they bring to the table is expertise. Since they do not do the full demolition this makes them more like a consultant early in the project, rather than a demolition company.

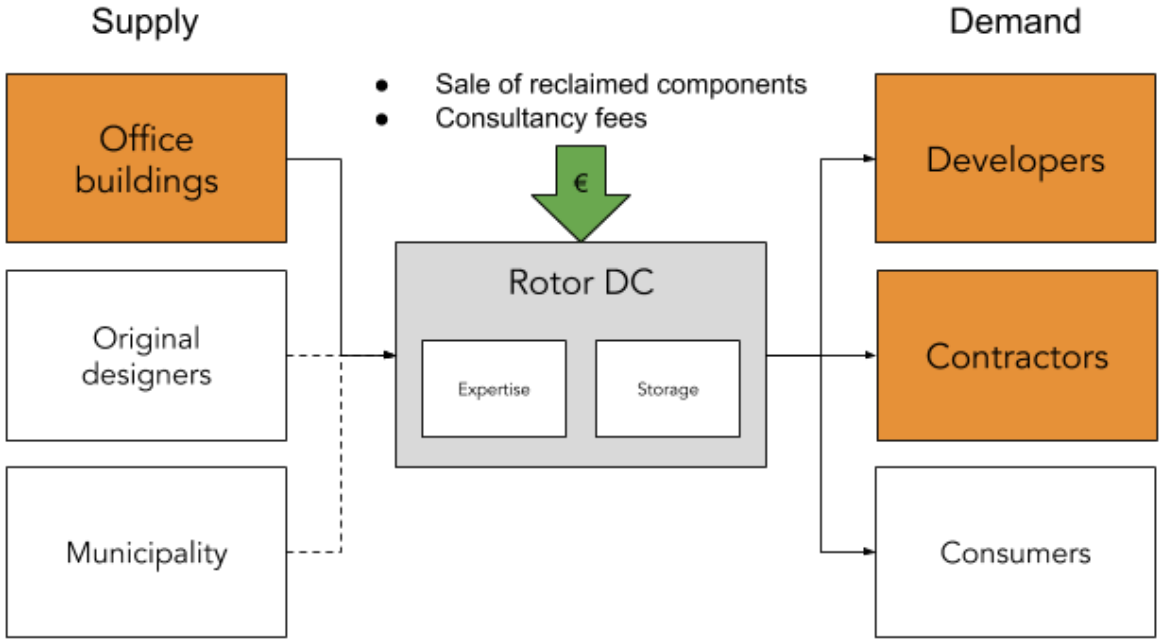

Figure 5.3: Role of Rotor DC in a demolition project.

Technology: Online presence

Communication technology is an important part of the strategy of Rotor DC. Every reclaimed component is listed on the webstore, this vastly increases the outreach of Rotor DC and thereby the chance to find customers for the reclaimed components.

Criteria for reclamation

Whether or not building components are reclaimed for reuse by Rotor DC was initially based on two criteria. First of all, components need to be suitable for disassembly without damage. Secondly there needs to be demand for the component once it has been reclaimed. At a later stage a criterion for profitability was added. This criterion is more complicated and could only be defined adequately after gaining the necessary experience. The profitability criterion takes into account the sum of man hours, transport, storage costs, and if needed remanufacturing costs. After taking these factors into account the minimum price is determined and the expected selling price should cover the costs.

Risks

By reclaiming and transporting building components to their depot without prospective buyers Rotor DC takes a financial risk. This risk is mitigated by the strict reclamation criteria outlined above which increase the chances for resale.

Materials in consignment

Traditional demolition companies can use Rotor DC's platform and storage space for selling components that have been reclaimed in-house. Thus far this service is rarely used (L. DeVlieger, personal communication, May 14, 2018), but it forms an important part or Rotor DC's strategy for the future.

Subsidies

Rotor DC does not receive any direct subsidies, but their depot and office space are rented from the municipality under favourable conditions. The rent price per square meter is a little under the usual price, but this is a temporary situation since the site will be redeveloped in four years (L. DeVlieger, personal communication, May 14, 2018).

Supply chain

The many different activities of Rotor DC mean that they are present in almost every step of the supply chain of the reclaimed materials. They usually work directly with the building owner and the identification and extraction steps are carried out before a separate demolition company takes over the remainder of the demolition process (L. DeVlieger, personal communication, May 14, 2018).

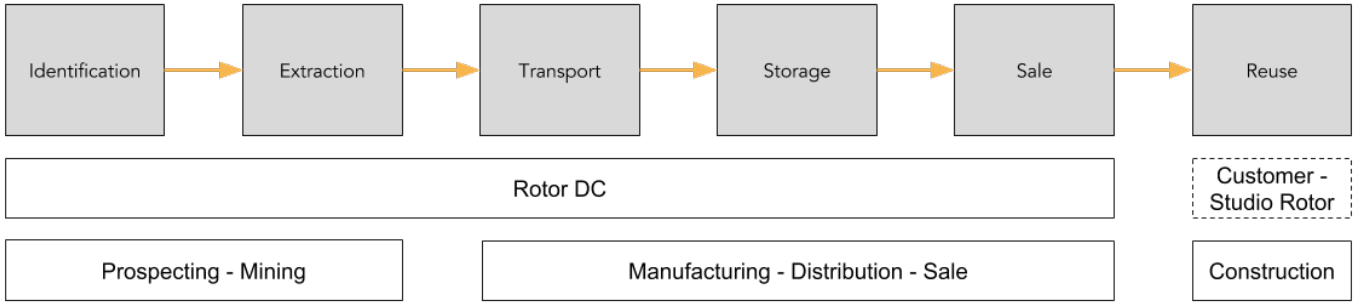

Figure 5.4: Placing Rotor DC in the supply chain of reclaimed components.

Process

- Pre-demolition audit

Before the demolition of a building commences a team of experts from Rotor DC visits the building to identify components that have resale value. This audit is purely a visual inspection and requires considerable expertise from the auditors.

- Use iPad app for documentation

To guarantee a consistent documentation method an iPad app has been developed for entering the made observations.

- Test disassembly

Deconstruction is a process with many uncertainties. These uncertainties involve matters such as: components breaking at disassembly; health risks; To get a feel for challenges that might arise during the full deconstruction Rotor aims to do test disassemblies of components. Since not every component has aged the same way, a successful disassembly does not guarantee the successful disassembly of the full batch, but it can help to identify the difficulties.

- Marketing

Marketing of the reclaimed components is a vital step in the process of reuse. The place in the process that it gets reveals a lot about the goals of the company. For Rotor DC marketing starts after the reusable components have been identified but continues until the components have been sold. The focus on high quality components in combination with the experience of the auditors means that components rarely go unsold.

- Deconstruction

Since Rotor DC does not fully replace a traditional demolition company, 'deconstruction' is an extra step in the demolition process. Before the traditional demolition companies come in a team from Rotor DC disassembles all the components that have been identified earlier.

- Re-manufacture

This step can be limited to sorting and cleaning the reclaimed components, but in many cases, this is a much more involved process. Rotor DC's specialisation in high quality materials has often resulted in the reclamation of bespoke building components that come with a story. A site visit revealed many batches of components for which the people of Rotor had dug into the history. Among them were floor tiles reclaimed from a municipal building in Antwerp that were meant to be laid in specific patterns. The original designs of the tile floors are part of the deal for any prospective buyer.

- Storage

Since storage is a costly step in the chain it is to be minimised wherever possible. Rotor DC has the advantage of having a cheap storage location.

- sale

Involved process; lots of uncertainties;

Main Drivers

In 2012-2013, Rotor conducted a survey of all existing dealers of second hand building materials in Belgium. They concluded that there was an opportunity in the market for facilitating component reuse with a focus on high quality materials leads.

Preservation of Embodied Energy

According to Lionel DeVlieger the main environmental driver for Rotor DC is the embodied energy of building components. At the time of production energy has been used for the production of the components. By discarding them new energy will have to be used for the production of new components, in case of reuse the embodied energy is preserved.

Economic

Rotor DC is an independent business and therefore needs to make profit. Even though profit was not an initial driver at the founding of Rotor DC, this driver is important as it allows the company to work independently.

Historic preservation of design

Since the Rotor DC initiative grew from the minds of architects preserving design is an important driver. Where possible the original plans are studied to make sure that unique building details are not lost in the demolition. Rotor DC aims to resell reclaimed components that have architectural value with information on how to preserve this value included. In my visit to the depot Lionel DeVlieger showed me the design patterns of tiled floors. The tiles were encountered in a university building in Liège, after which the designs were

found, and the tiles could be sold with the original designs by Joseph Moutschen (L. DeVlieger, personal communication, October 2, 2017).

Main Barriers

The way Rotor DC is set up is to avoid barriers and find ways around them, rather than overcoming them. This has proven to be a smart strategy for the time being, but it begs the question for how long. Their ambition is to eventually be able to reclaim 5% of a building by mass for reuse. Currently they manage to reclaim 1-2% (L. DeVlieger, personal communication, October 2, 2017). The barrier for expansion is a lack of demand and their limited area of operating, because of exclusion of risky components.

Work intensive

Rotor DC calculated that the circular demolition methods require up to seven times more personnel than traditional demolition methods. This can be a serious barrier to the economic feasibility of disassembly activities.

Uncertainty of reclaimability

Health risks

The inventory and demolition of a building involve many health risks. Virtually all buildings constructed before the 1990's have asbestos present somewhere in the building. Examples of other health risks include wooden floors. These kinds of floors were often mounted on a bitumen subfloor, if this subfloor contains tar it is carcinogenic (L. DeVlieger, personal communication, October 2, 2017). The presence of these toxic substances in buildings makes the recovery of components an uncertain business, because as soon as they are encountered the components containing it are not suitable for reuse anymore.

Damages

The disassembly of components can often lead to damages of the components themselves or other parts of the building (L. DeVlieger, personal communication, October 2, 2017).

Opportunities

As a company Rotor DC was called into life to exploit new opportunities with respect to component reuse. It is therefore no surprise that most of the initially identified opportunities have already been integrated into the practices of the company. Nonetheless there are some opportunities that have been identified but have yet to be exploited.

Taken Opportunities

Manages to turn a profit.

The first inventory made by Rotor was commissioned by an external real estate company that specialised in offices ('Rotor Deconstruction | Henry van de Velde Awards', 2016). The initial goal was to identify components in a big office building that could be reused. When the client decided that the operation had to pay for itself, Rotor focussed attention on only those components of which the resale would be able to pay for their own disassembly. This turned out to be a substantial amount of materials and they took the opportunity to transform this discovery into a business. The reclamation, remanufacturing, and sale of high quality building components that are not antiques proved to be an opportunity thus far not taken by other companies. Rotor DC has found a new use for over 700 tonnes of components.

Refurbishments

The inclusion of Rotor DC in a full demolition project requires an additional party, the regular demolition company, to take over after the pre-demolition, thereby increasing the number of parties and contracts needed. In a refurbishment however, Rotor DC can fully replace a demolition company, provided that no structural elements need to be taken out. This can be the case in office buildings that will get a new occupant, since for these types of buildings it is standard procedure to strip the interior for the new occupant.

Identified Opportunities

Just in time delivery has been identified as a big opportunity to save costs on transport and storage. While their initial business model favoured direct sale from the demolition sides, it proved to be difficult to find buyers at the right time. The opportunity remains however.

As of 2017 Rotor DC skims about 1% to 2% percent of the materials from a building by weight. Their ambition is to increase this to 5%, but according to DeVlieger this is not yet a realistic goal. Rotor DC does not have the ambition to reclaim all building components for reuse, but rather aims for a mix between re-

use and recycling, where they are only involved with the materials and components that will be reused.

Professional market

Rotor DC has a broad network in the professional construction market, but nonetheless sells most of the reclaimed components to small projects. A reason that has been identified is the inability to deliver large batches of identical components. Rotor DC has identified product groups that could be reclaimed and reused in batches. Sinks are a component that satisfies these criteria.

Portfolio mining

To be use components as efficiently as possible Rotor DC wants to enter into a contract with a real estate owner. Then it would be possible to make an inventory of components like sinks, that can be easily reclaimed and reused. The inventory would allow for the reuse of these components within the portfolio of the real estate owner. Because there would be no change of ownership a lot of problems could be avoided (L. DeVlieger, personal communication, October 2, 2017).

Exemplary role of governments

Lionel believes that a big opportunity for the adaptation of circular demolition can come from the government setting an example. In Flanders it is already mandatory to make an inventory of the construction and demolition waste in demolition projects. If the government wants to encourage circular demolition it would be smart to make a reuse analysis mandatory as well (L. DeVlieger, personal communication, October 2, 2017).

Concluding Comments

While it is indisputable that Rotor DC adds value to the materials by their process of remanufacturing and their services, the business model of receiving these components without monetary compensation for the current owner is bound to expire if circular demolition becomes more mainstream. The question should be asked whether the removal of the most valuable components from buildings, makes the remainder of the buildings less profitable for the demolition company that will take over the demolition process after Rotor DC is done. Currently however this way of working allows Rotor DC to gain experience in the valuation and reclamation of building components while building a network of real estate owners, demolition companies, and customers for the reclaimed components. Furthermore, the sharing of experience with other companies, governments, and academics is an important part of Rotor DC's activities. Since Rotor DC works at the cutting edge of the developments in component reuse, the company is in constant flux and adapts its business model to the developing market. The consignment programme is a first step to stay relevant if or when demolition companies decide they no longer want to give away valuable components for free.

Having an architectural firm in the same company seems to be a great benefit as the components that have not found a buyer yet are always under the eyes of the designers, prompting them to come up with creative ideas for reuse within their own designs.

5.1.2 Bouwcarrousel

Figure 5.5: Depot of Bouwcarrousel (Vermeiren, 2011)

Bouwcarrousel bv
duurzaam slopen, revisie en hergebruik

Figure 5.6: Logo of Bouwcarrousel

Bouwcarrousel (fig. 5.6) was a company, founded by Rob Gort, with the goal of facilitating reuse of building components by means of deconstruction. It was set up as a full alternative to demolition companies offering the full circular demolition of a building except for the frame. Since Bouwcarrousel was able to replace all but the structural-demolition company, they were able to charge for their deconstruction services. While the original intention of the company was to turn a profit from the components sold for reuse, in reality the largest share of revenue came from charging for deconstruction services. This is not to say that the company was unsuccessful, rather the opposite. Bouwcarrousel operated from 2000 until its bankruptcy in 2010. In this time many circular demolition projects have been completed successfully, one of them a full neighbourhood of 430 houses in The Hague. Even though selling the reclaimed components to professionals within the Netherlands proved an obstacle, this was initially overcome by expanding sales to the rest of Europe, going as far as partnering up with a Romanian contractor to become the direct supplier of building components for several social projects in Poland. In spite of the initial success, the way Bouwcarrousel operated made it vulnerable to business cycles. The low demand for reclaimed components meant that even in good times more components were coming in than going out. Due to shrinking demand for both demolitions and new buildings Bouwcarrousel filed for bankruptcy in 2010 during the housing crisis.

Business model

The existing market in reclaimed building components was identified by Bouwcarrousel and used as a starting point for the development of their business model. At the time of writing the business model, a market in reclaimed building components existed in the Netherlands but it was very small and limited to a subset of components.

When the founder of Bouwcarrousel, Rob Gort, was commissioned to compile a report on promotion of sale of reclaimed building components by the provincial government of South Holland, he noted that the supply of Construction and Demolition Waste was bigger than the supply of conventional domestic waste for which many reuse initiatives exist that are actively supported with policy and subsidies.

Supply analysis

In spite of the large supply of Construction and Demolition waste, trade in reclaimed materials is very small compared to trade in new construction materials. Traditional demolition companies do not do a lot of disassembly of components, with exception of components that can be easily sold in the market for building restauration.

Bouwcarrousel aimed to have a big supply of components that are not traditionally reclaimed and are not readily available from the second-hand market. The focus is put on standardised components that are available in large quantities in social housing projects like: sinks, doors, window frames, light switches, radiators, etc. The components are disassembled in a pre-demolition in which the building is stripped and only the building structure remains. This requires the full demolition to be done by a second company. While it is not conventional to divide a demolition project into multiple contracts this has not stood in the way of getting projects (Vermeiren, 2011). Bouwcarrousel is capable of doing the non-frame demolition and also takes care of non-reusable materials.

Role in a Project

The involvement of Bouwcarrousel in a project means that they can give their input in from the planning phase up towards the pre-demolition, after which a different company will take over to finish the demolition of the structure. Being involved from the planning phase allows Bouwcarrousel to be heavily involved in the preparation work before the demolition takes place, this is further explained in the section on disassembly process.

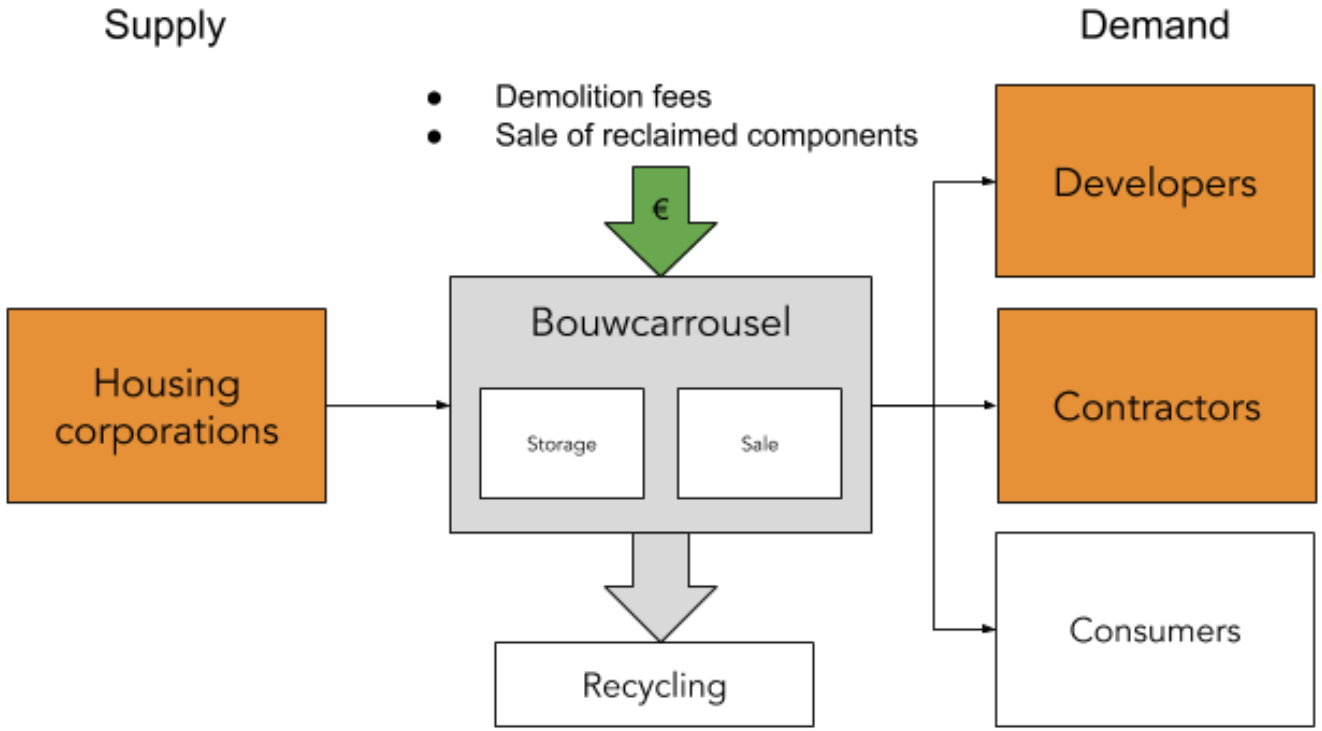

Figure 5.7: Role of Bouwcarrousel in a demolition project.

Criteria for reclamation

Bouwcarrousel takes reclaimability and technical suitability for reuse of components as the main criteria for reclamation. They take in everything that can be disassembled in a manner that leaves it usable after disassembly, this is usually up to 40% of the building. The matching of supply and demand happens after transport and storage and potential demand is not a criterion for reclamation in the first place.

Strategies

The criteria for reclamation used by Bouwcarrousel result in a of two waste streams leaving the demolition site. One being the materials designated for reuse, the other materials designated for recycling. Separation of the streams and within the streams happens on-site.

Technology: Online presence

Both Bouwcarrousel and Rotor DC have business to business sales as their first priority. In spite of this both companies set up direct to consumer sales. Bouwcarrousel in the shape of a warehouse with the contents indexed in a database that can be consulted online. Rotor DC in the form of a real showroom with the products indexed online with pictures and an option to buy online.

Risks

The business model of Bouwcarrousel rests on the assumption that demand for reclaimed components will increase over time. The principal risk to this strategy is a stagnation or decline of the already low demand for reclaimed components. Additionally, a decline in demand for demolition in general, as happened in the housing crisis, can amplify this effect. Since the reason for Bouwcarrousel to exist is the stimulation of component reuse, this is a difficult risk to account for without touching the fundamentals of the business.

Subsidies

Bouwcarrousel did not receive subsidies for their reuse practices, but since it was active in other areas of social responsibility it did receive subsidies for the hiring and education of employees from probation. In addition to this the building projects in eastern Europe received support from various foreign governments and NGOs (Vermeiren, 2011).

Supply chain

The facilitative nature of Bouwcarrousel places it in different places in a supply chain depending on the activity.

- Reclamation activities place Bouwcarrousel in pre-demolition, an extra step that fits in before the full demolition of a building.

While it is not common for the demolition of a building to be divided into two separate contracts the added steps are necessary for the disassembly process and would be added in if the process was carried out by a single company as well.

- Resale activities place Bouwcarrousel as a supplier in the supply chain of construction projects incorporating their components.

- Construction projects make Bouwcarrousel both a supplier and a contractor.

Process

- Contract

- Pre-deconstruction assessment

Before the deconstruction of a building commences an expert from Bouwcarrousel submits the building to an extensive visual inspection. The main purpose of this inspection is to build an in-

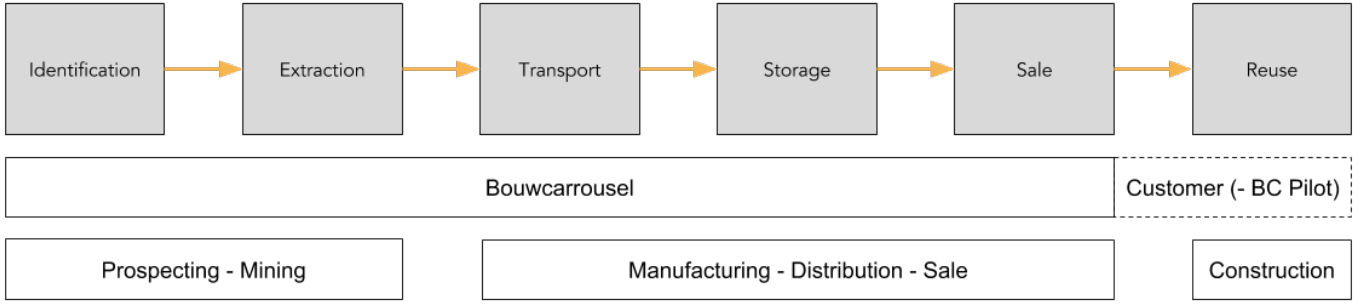

Figure 5.8: Bouwcarrousel's place in the supply chain.

ventory of the materials and components that can be reclaimed for reuse. This assessment is made based on technical drawings as well as the visual inspection, but according to Rob the real reusability can only be determined by visual inspection.

- Offer

After the inventory has been made. Bouwcarrousel makes an offer to the client.

- Demolition

Bouwcarrousel fully takes over the demolition activities. The order of disassembly is slightly different from traditional demolition processes. After the windows and window frames have been dismantled the buildings are closed off to avoid theft of components. After this step all components that can be removed without breaking are taken out and placed into sea containers.

- Re-manufacture

This step is limited to mainly the cleaning of components.

- Storage

Bouwcarrousel uses shipping containers for the storage of batches of reclaimed components. The components are preferably sold as full containers. Unsold containers are stored.

- Cataloguing, marketing, and sale

Marketing and sale is mainly focussed on finding buyers abroad where markets for secondary materials are better. For consumers the contents of every container are listed in spreadsheets that can be downloaded from the website. Components are not listed on external websites since it was found that this led to few extra sales.

Main Drivers

Rob Gort noted that demand for secondary components in the Benelux was low in the years that his company was active. The answer of Bouwcarrousel to this problem followed the reasoning that demand would never pick up without adequate supply. Bouwcarrousel reclaimed and stored all the components they deemed fit for reuse. On average this would be about one third of the total building mass, excluding frame (R. Gort, personal communication, Mei 19, 2017).

Societal/behavioural/environmental

The motives of Bouwcarrousel were first and foremost societal in nature. Even though Bouwcarrousel was a fully-fledged company, it was also very much a passion project of one man. Therefore, the decisions made for the company as a whole, while always adequately justified from an economic perspective, can often be reduced to behavioural drivers from Rob Gort. While Bouwcarrousel was first and foremost a company focussed on environmental sustainability, corporate social responsibility was also highly important. Workers were often sourced from probation and educated internally (Vermeiren, 2011).

Environmental

The drive to find new destinations for reclaimed building components is what lead to the founding of Bouwcarrousel. By disassembling buildings rather than demolishing them, Rob Gort wanted to make sure the materials would not go to waste (R. Gort, personal communication, Mei 19, 2017).

Economic

Even though the primary drivers of Bouwcarrousel were not economic in nature, the company was fully professional company with an economically viable business plan. The fact that the company eventually went bankrupt should not be taken as a measure of failure without deeper knowledge of the circumstances.

Main Barriers

According to Bouwcarrousel and Rotor DC the selection of components for which demand can be found requires experienced disassemblers. Both Rotor DC and Bouwcarrousel use experienced professionals to identify the components that are likely to have demand.

The perceived value of reclaimed components is apparent in the facilitating cases. Lionel DeVlieger stated that they have to sell washbasins of high quality for low prices because they compete with cheap newly produced products that are of inferior quality. In a similar vein Rob Gort from Bouwcarrousel experienced a low demand for high quality building components, partly due to the image of second-hand components. The same conclusion was reached by Pomponi & Moncaster (2016) who not that people do not want to buy components for their fancy new buildings at the scrapyard. The two client cases of RVB and Erasmus MC confirmed these statements in an interesting way with people stating in informal and formal interviews that low quality of recycled components is a barrier to reuse, while other agreed that it was a problem of perception. Iacovidou & Purnell (2016) expect that

the “changes in the perceived value of reclaimed construction components are likely to increase demand for these components in the near future”.

Perceived lower quality of reclaimed components

Reclaimed components have a lower perceived quality than new components (Densley Tingley, Cooper, & Cullen, 2017). RotorDC manages to find new destinations for many components because of their focus on high quality. Even so, they have trouble competing with new components of lower quality and a higher price. An example of this are sinks of high quality manufacturers in pristine condition. Rotor DC has enough of these sinks in stock to outfit some moderately sized buildings. This is exactly what they are planning, but thus far potential buyers seem to prefer cheaper made new products.

In a similar vein Erasmus MC will deconstruct two buildings while aiming for a reuse rate that is ambitiously high. Even though the reclaimed components are of high quality and some of them have historic value to the hospital, the choice has been made not to reuse any of the reclaimed components onsite because of quality requirements for the new hospital.

On the other hand, while Bouwcarrousel has struggled with the same issues in the Netherlands, they have found the opposite to be true in countries of eastern Europe. According to Rob Gort the perceived quality of reclaimed German made materials is higher than that of new Chinese made materials. Hence, the sale of many containers full to other countries where the perception is different.

Governmental

Rob Gort argues that the high taxes on labour in the Netherlands make it more difficult to compete with products that are cheaply produced in low wage countries. Since the labour required for the reclamation is comparable to that of producing new components. Furthermore, reclaimed components are taxed on their sale just like new components, even though they were already taxed for their first sale (R. Gort, personal communication, Mei 19, 2017).

Opportunities

During the time it operated Bouwcarrousel was a pioneer in circular demolition and attempted to exploit opportunities with regards to component reuse. During the company’s lifetime several different approaches have been taken to alleviate the lack of demand for reclaimed components with varying degrees of success. In addition, the eventual bankruptcy has lead Rob Gort to reconsider the route that the company took leading to fresh insights.

Taken Opportunities

The market for second hand construction materials and components is not big. However, within this market there are niches that can count on a consistent supply and demand, such as antiques. The focus of Bouwcarrousel on social housing projects led to the reclamation of low to medium quality components that would otherwise not be reclaimed. This lack of overlap with other markets for reuse means that Bouwcarrousel has managed to find its niche and is contributing to a more circular construction industry.

Construction projects

In addition to finding customers abroad, Bouwcarrousel attempted to expand the domestic market by offering their services as a construction company, thereby using their own stock of reclaimed components.

Foreign aid

By partnering up with Non-Governmental Organisations, Bouwcarrousel contributed to projects in eastern Europe and Africa. This allowed Bouwcarrousel to create demand for the reclaimed components in its storage. These foreign aid projects were a response to the discrepancy between supply and demand of reclaimed materials. While the circular demolition division of Bouwcarrousel was successful in reclaiming useful components from buildings and turning a profit, the other side of the company suffered from an increasing stock of components without an increase in demand. After offering construction services within the Netherlands, alternatives were sought to find a new destination for the reclaimed components. While this resulted in several successful projects, the practise did not result in any long-lasting partnerships (Vermeiren, 2011).

Identified Opportunities

The supply of components forming the core business of Bouwcarrousel was previously untapped. Public housing and the big amounts of mass produced components used in them form a big opportunity for component reuse. Bouwcarrousel aimed to reclaim everything that could be reused for reuse, which by their estimate came down to about one third of the building. While sever-

al markets for the sale of these components have been identified by Bouwcarrousel, none of them proved to have sufficient demand compared to the supply. There is still an opportunity to utilise this supply if demand for these kinds of components increases, or a new market is identified.

Bankruptcy

The bankruptcy of Bouwcarrousel had the results of not accounting for these risks played out in real life. Demand never caught up with the supply available from Bouwcarrousel and at the time of bankruptcy seven warehouses full of reclaimed components had been filled. While this fact makes it easy to dismiss the initiative as a failure, many construction companies filed for bankruptcy during the financial crisis of 2008. In fact, the number of bankruptcies of construction related companies reached its peak in 2010, jumping 20% from the year before ('StatLine - Uitgesproken faillissementen; kerncijfers', 2018). The timing of the bankruptcy means that it cannot be attributed solely to the business model of the company. While the build-up of components in warehouses is unsustainable in the long term and had not been solved at the time of bankruptcy, it would be by no means unsolvable.

Figure 5.9: Advertisement for Bouwcarrousel as a contractor (Puur Bouwen, April 2005).

Concluding Comments

In setting up Bouwcarrousel at the turn of the millennium, Rob Gort was ahead of his time. He succeeded in creating a business that could operate in circular demolition projects and found demand for their services. Demand for the reclaimed building components was lagging behind but the company was involved in some sizeable demolition projects and innovative construction projects. During its run profit was made on the demolition services, rather than resale of reclaimed components. At the time of bankruptcy there were 160 containers left in storage, which accounts to about 60% of the components that had been recovered over the lifetime of the company.

In spite of the bankruptcy an array of opportunities was identified. A potential market in eastern Europe was identified and to some extend exploited, but it proved difficult to get a permanent foothold, because most of the partners did not specialise in housing projects.

The criteria for reuse used by Bouwcarrousel have become problematic in the long term, after all if there is no demand for the components being stored, would recycling not be a better approach?

5.1.3 A. Van Liempd Demolition Companies

Figure 5.10: Van Liempd at work in Winterswijk (Photo Van Liempd, 2018)

Van Liempd is a demolition company with almost thirty years of experience. In contrast to the two circular demolition companies from the first two cases, Van Liempd was started as a traditional demolition company and is able to provide full demolition services. While working for another demolition company Arie van Liempd discovered that there was a demand for the components from the buildings he demolished among the farmers in the neighbourhood who were expanding and building barns. This lead him to found his own company as a sustainable enterprise in which, the reuse of components got attention through the entire process.

Corporate structure

Van Liempd is a holding company with two subsidiaries: Van Liempd Sloopbedrijven and Gebruiktebouwmaterialen.com. This structure allows the circular demolition company to directly sell the reclaimed materials to their sister company, thereby delegating the risky and lengthy process of remanufacturing and selling the components away from the demolition company.

Business model

The Van Liempd Demolition company is structured much like most traditional demolition companies. In contrast to Bouwcarrousel and Rotor DC it was founded in the first place as a demolition company, with circular demolition as a secondary goal. Because of this more pragmatic vision the business model is focussed on being economically viable, rather than maximising component reuse of their demolition projects.

Maximisation of component reuse does take place but is mainly rooted in economic drivers. Because of their unique corporate structure, Van Liempd is positioned perfectly to take advantage of opportunities for component reuse when they arise. Because making profit on reclaimed components is one of the ways in which Van Liempd stays competitive, there is a big incentive to find additional profit in this area.

Just like Rotor DC, Van Liempd has recently opened up its platform for selling components to third parties. This allows the platform, gebruiktebouwmaterialen.com, to grow independently of Van Liempd Demolition, but arguably more importantly stimulates the growth of component reuse.

The lion's share of reclaimed components is sold to small projects and individuals. Just like Bouwcarrousel tried, and like Rotor DC is actively pursuing, Van Liempd is attempting to break into the market for bigger professional construction projects.

Van Liempd has a full sawmill on site and is specialised in repurposing wooden components. Oftentimes reclaimed wooden beams can be cut into smaller beams that could pass for new. The quality of the old wood in question is often higher than the quality of wood from young trees that were recently cut down in production forests. By the company this is considered reuse since recycling is often open-loop recycling, but it might better be classified as closed-loop recycling, since a new and equal use is found for the material, but the components are not kept intact.

Role in a Project

Van Liempd Demolition is a demolition company and has the demolition of a building as their main activity. They are specialised in circular demolitions and therefore integrates the reclamation of components within the project from the start. Because of this it does not usually take them longer to demolish a building in a circular way than it would take another company to demolish the building in a more traditional manner. As the demolition company they are in charge of the demolition of the building and the processing of all the materials. For the reclaimed components this is done through resale by their sister company, materials that are recycled are transferred to other companies that specialise in waste processing.

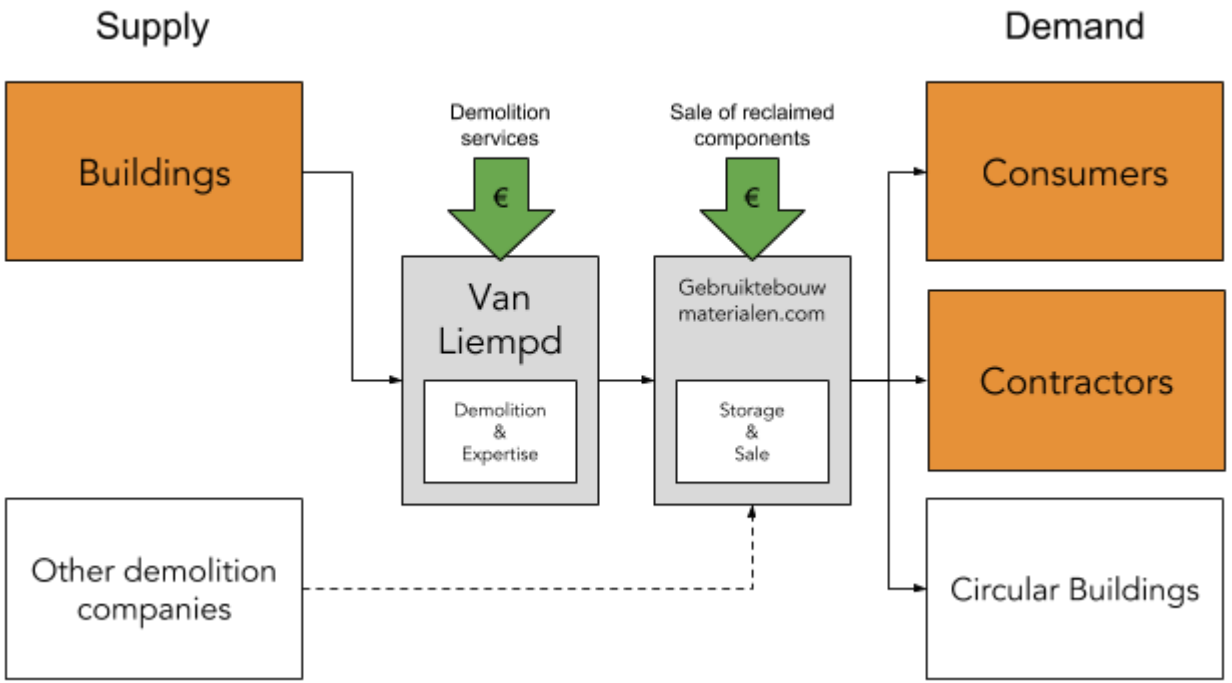

Figure 5.11: Role of Van Liempd in a demolition project.

Strategies

Reclaiming everything that is sellable and by doing so being cheaper than other demolition companies. The price for a bid is calculated based on the demolition costs minus the expected profit from resale of components.

Criteria for reclamation

All the components that are reclaimed need to be sellable. The decisions on which components are designated for reclamation in a bid are based on their experience. Since the expected profits from these components are largely discounted on the bid the selection is relatively strict. However, in the process of the circular demolition they will keep an eye out for opportunities and often reclaim extra components. In the case of Winterswijk an opportunity was seen in the reclamation of carpet tiles, which were reclaimed without certainty of sale, but turned out to be easy to sell.

Process

- Inventory

The inventory of which components are reclaimed is mainly based on a visual inspection in combination with experience. In cases that an external firm has already made an inventory this is used in the process, but often the agency who made the original inventory lacks the experience to adequately appraise the components. The original inventory is used as a reference book in the inventory process.

- Demolition

Since van Liempd does the whole demolition this is a single step in the process, but different components still require a different demolition method. The components that will be reclaimed are dismantled first

- Transport of reclaimed components

- Storage and sale of reclaimed components

After the components have been transferred to the depot they are listed on Gebruiktebouwmaterialen.com. Especially for wood it is common to have a remanufacturing step in between reclamation and sale.

- Evaluation

If the company that hired Van Liempd for the demolition of their building shows an interest, Van Liempd reports on the state of sale of their reclaimed components some months later. The paper trail of where components are sourced from and sold is an important tool for Van Liempd, as it allows them to show the added value of reclaiming components to both source and eventual customer.

Main Drivers

In its core, Van Liempd is a demolition company with circular demolition as the goal of van Liempd is to use the income generated by reclaimed components to be cheaper than other demolition company and compete with them on price while also being circular. This sets them apart from the two facilitator cases discussed earlier in this chapter by having economic viability as a principal driver.

Main Barriers

Lack of demand from businesses

Around 80% of the reclaimed components are sold to individual customers. Even though the remaining 20% is sold to businesses it has proven to be difficult to really break into the business to business market with used components. Van Liempd is attempting to increase interest from the businesses that they work with for demolition, but in most cases their interest in circular demolition is limited to the demolition side of things.

Building code

For the sale of used components there are not a lot of regulations. Buildings that are newly constructed, however, need to be up to code. This means that in addition to the supply difficulties of selling reclaimed components to businesses, the building code makes it very difficult for certain components to do so. Reclaimed window frames, for

example, were often made in times with different regulations for insulation. So, developers of new buildings are prevented from using them without adaptations, making it easier to use new window frames instead with double-, or even triple-glazing.

Competitors without experience

It happens often that other companies participate in a tender and make big promises with regards to circular demolition, but their lack of experience causes the promises to get lost in the process.

Shipping costs

Because they sell online, Gebruiktebouwmaterialen.com is bound to the general rules for e-commerce. This includes taking back items within two weeks if the customer does not want them after all. Because of the nature of construction components shipping costs are often high, providing a barrier to this service. Nonetheless, customers are buying the components in spite of the shipping costs and the return rates are low.

Opportunities

Taken Opportunities

Active online sales

Having a strong online presence is an important way to make sales. At Gebruiktebouwmaterialen.com a fulltime employee is devoted to the upkeep of this online presence. Rather than limiting this to their own website, every component available is also added to other platforms to increase discoverability, in addition to this there is a strong attention to Search Engine Optimisation (SEO).

Quality of Reclaimed Wood

The general quality of reclaimed wood was discovered to be higher than that of most wood currently on the market. Because of this hardwood doors can be sold for profitable prices, but this difference in quality is not limited to hardwood, even regular timber beams can be resold easily. As added value they are the only company in Europe that sells FSC certified reclaimed wood. Instead of the wood being traced back towards the original forest, the wood is traced back to the building from which it was reclaimed.

Extra reclamation during demolition

During the circular demolition it is common for the workers to come across components that were not designated for reclamation but are suitable for it. Because of the experience present in the company, they are able to use this to their advantage and reclaiming more components than originally planned. These components are also listed, and this happens in communication with the client.

Identified Opportunities

Business to business sales

Van Liempd is actively working to expand its business to business sales, by creating awareness. They do this by approaching circular projects, architects, and current customers of their circular demolition services. Currently the interest is growing, but there is still a long way to go. Everybody is interested in circular demolition because it creates value from something that has been written off. The problem with the lack of demand from businesses is that value cannot be created without a functioning market.

Concluding Comments

Unlike Bouwcarrousel and Rotor DC, Van Liempd is a company that has been comfortably operating within its niche for over thirty years. In spite of, or perhaps because of a different main driver from the other facilitator cases, they have thrived economically, while at the same time growing their component reuse business. However, where Rotor DC and Bouwcarrousel are constantly pushing the boundaries of what is possible with regards to reclamation and component reuse, Van Liempd is more focussed on proven methods, but will take opportunities when they present themselves.

5.1.4 Government Real Estate Agency

Figure 5.12: Office of the Government Real Estate Agency.

The Central Government Real Estate Agency (RVB) is the real estate division of the Dutch government. Its responsibilities include the management and conservation of real estate in use by the Dutch state. The agency manages a portfolio of over 12 million square meters with a total value that exceeds 15 billion euros.

From their role as a government agency they aim to do more than just manage the real estate and often try to set an example by being at the forefront of new developments. Circular demolition and by extension component reuse is one of the developments that receives extra attention from RVB.

Pilot: Circular Demolition Tax Office Winterswijk

Following the adage reduce, reuse, recycle, the government real estate agency attempted to find a new use for the old tax office in Winterswijk. After failing to find a new use, the RVB decided to demolish the vacant tax office. Later, it was decided that this project could serve as the first pilot for circular demolition of an RVB property. RVB's internal experts decided on the focus for this demolition and award criteria for disassembly and resale were included in the tender.

The consultancy firm BOOT was commissioned to make an inventory of all the components in the building and make an assessment of their reusability. This inventory was used by the five demolition companies, in addition to their own inventories, for drawing up the offer.

The selected contractor was the one that scored highest on the reuse criteria and was, partly because of this, also the cheapest. Because the reclamation and resale of useful components were included in the offer, the costs for the remainder of the demolition could be adapted accordingly.

During the disassembly of useful components, as well as during the demolition of the structure, records have been kept of all outgoing components and waste streams. This way the actual reuse of the components can be checked. Materials that have been reclaimed and will hopefully find a new use include: window frames, doors, roof structures, air conditioners, and radiators. The circular demolition company, Van Liempd, has worked closely together with RVB to ensure that newly gained knowledge is retained within both organisations (B. Albers, personal communication, November 17, 2018).

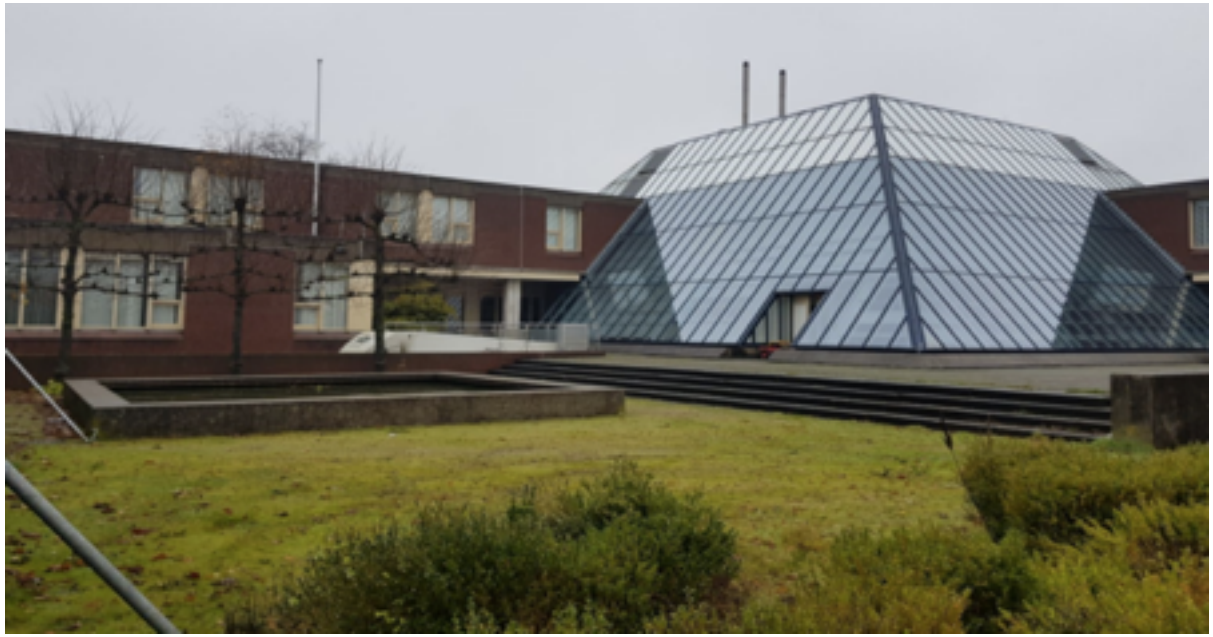

Figure 5.13: Former Tax office, Winterswijk.

Business model

Even though the RVB is part of the national government they are expected to act like a private company. The projects they are involved in should be economically viable in their own regard, so even special projects like a circular demolition project are tendered on price over the secondary criteria. The priorities for projects are based on their market vision, in which six focal points are introduced (Rijksvastgoedbedrijf, 2017). These six focal points are: collaboration, value for your money, purchasing and sales processes, sustainability, safety, and progressive. RVB uses these focal points in their interactions with market parties to increase trust and they form the foundation for their projects.

Supply chain

As a real estate agency RVB has traditionally been close to the end of a linear supply chain, as the client that commissions the buildings. In the transition to a circular supply chain however they find themselves in a different position. In the pilot project, the demolition of the office building can be seen as the first step of a new linear supply chain. From this vantage point the circular tax office in Winterswijk takes the place of a mine. The company excavating the mine is Van Liempd, they extract the components and materials from the building. The components designated for high quality reuse are sold to gebruiktebouwmaterialen.nl a separate company owned by Van Liempd Holding B.V. This company does the transport, storage, and sale of the reclaimed components, thereby taking the place of manufacturing, distribution, and sale.

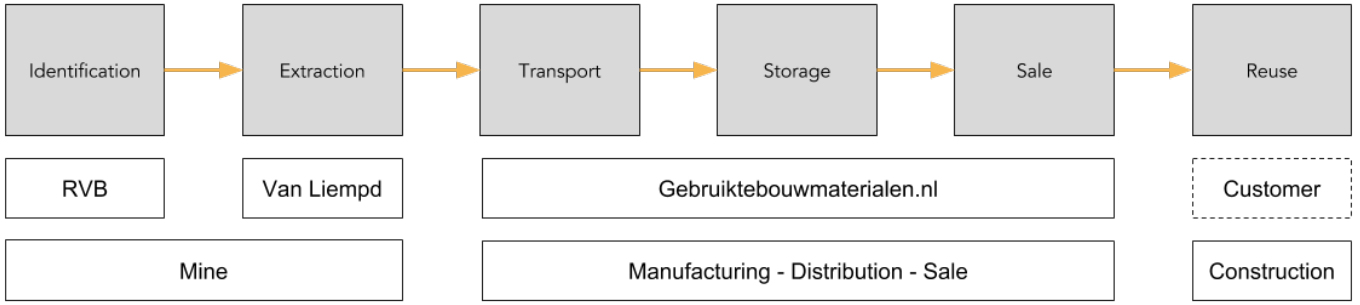

Figure 5.14: Supply chain of the circular demolition pilot

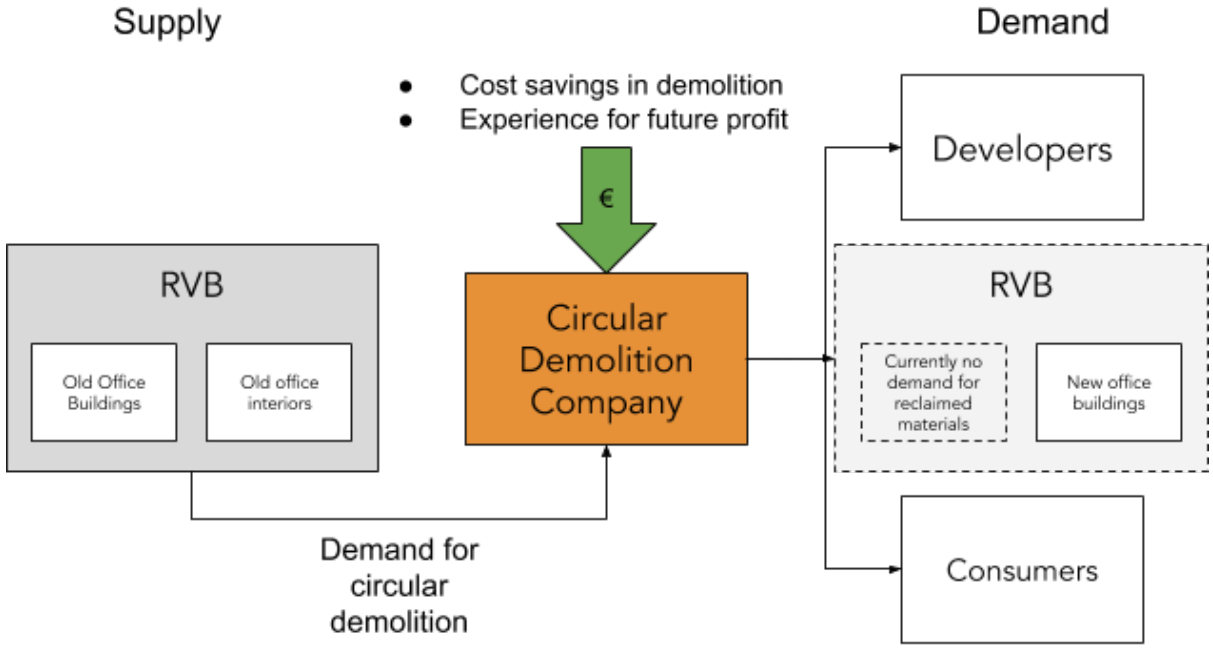

Figure 5.15: Place of RVB in this and potential future projects.

Role in the Project

In this project the government real estate agency is the initiator of the circular demand and the client.

Strategies

Even though the demolition project served as pilot to determine the viability of future circular demolition projects, the RVB aimed and succeeded in keeping costs down because the winner of the tender was also the cheapest. This was the case because the demolition company was able to subtract the expected profit from the reclaimed materials from the demolition cost in their offer.

Criteria for reclamation

Before writing out the tender RVB commissioned the mapping of the circular potential of the office buildings by an external party. The result of this was an assessment of components and materials that could be reused. The criteria for this assessment were quality, aesthetics, and technical lifespan. In addition to these criteria estimations were made about potential profit and a life cycle assessment was carried out to determine the environmental benefits. The economic criteria for reclamation were decided by the demolition contractor and were mainly based on their experience within the market for resale of reclaimed building components.

Risks

To mitigate risks a risk reward matrix was made by RVB with help of external consultants before the tender was written. This matrix was subsequently used to brainstorm about the best way for writing out a tender that includes risk mitigation while keeping circular ambitions high.

Subsidies

While no subsidies were involved in this pilot, RVB is part of the national government, making the incentives for the circular demolition a result from governmental actions. You could look at the transfer of the building components to Van Liempd as a subsidy, but since the tender was awarded on price as well as circularity criteria this is no very different from a traditional demolition company taking in the materials and paying to have them processed rather than profit from them.

Process

- Explore possibilities

A symposium was set up to explore the possibilities of component reuse. The focus of this symposium was to find out which information was important to have about buildings to make component reuse feasible in the cases of maintenance or demolition. The symposium included an organised brainstorm session to gather ideas from experts, students, and employees of RVB.

- Establishing ambitions

RVB decided that they needed more experience in order to meet the requirements set on waste minimisation by the government. As in many government-initiated plans, RVB wants to be ahead of the curve and set a right example for private companies.

- Pilot deconstruction

RVB started the realisation of their ambitions with regards to circular demolition with a pilot project in Winterswijk (fig. 5.13). No direct component reuse was done within the portfolio of RVB, but the demolition company that won the tender had identified the building component that would likely have value if dismantled properly and agreed to sell them. The cost savings of having less waste and possibility of resale of components were not separately negotiated but formed part of the overall offer.

- Evaluation

Since RVB aims to be a fully circular organisation by 2050 the primary objective for the pilot deconstruction is to learn things that can be applied in future projects. As such the objective can be compared to that of this study.

Main Drivers

The main driver of the government real estate agency for circular demolition is the conviction that it will become mainstream in the near future. Current projects are viewed as learning experiences and future profit and increased experience are considered more important than current profit. The national government has ambitions to close material loops (Schut et al., 2016) and the construction industry plays a big role in these ambitions. A goal cut construction and demolition waste by 50% in 2030 and achieve a fully circular economy in 2050 was formulated by the national government.

Policy

As a public institution RVB follows the ambitions of the national government and wants to purchase 100% sustainably. According the sustainability statement on their website this means that RVB uses reused and reusable materials as much as possible and does not use scarce resources at

all ('Duurzaam inkopen | Duurzaamheid en energie | Rijksvastgoedbedrijf', n.d.). In practise, however, this means that new projects mainly use reusable materials, rather than reused ones (B. van Dinther, personal communication, April 18, 2018).

Circular demolition

Policies set by the national government are an important driver for the government real estate agency to implement circular economy principles within their organisation. The internal vision on circular economy mainly covers energy use but expands with circular economy goals on not using scarce materials and reusing materials. The goal to reduce waste in the construction sector has been taken very seriously and has led the organisation to start a pilot with circular demolition.

Main Barriers

With the government guidelines for waste minimisation as the principal driver, a barrier becomes apparent immediately. The waste minimisation guidelines do not make a distinction between recycling and reuse. However, this distinction was made in the pilot in Winterswijk.

Storage

Temporary storage of the reclaimed components is a necessity until they can be sold to a new user. This adds costs to the reclaimed components by requiring more transport and a depot. Since storage of materials and components does not fit in the core business of RVB nor of most demolition companies this can be outsourced to another company.

Legislation

The requirement for tendering makes the sale of reclaimed components difficult for RVB directly. In the orientation phase of the pilot an interested party had been found for the kitchen of the building tax office but due to the necessity to write out a tender the sale of reclaimed components went to go through van Liemd, the winning demolition company without direct influence of RVB. Similarly, in the same project the different demolition companies competing for the tender identified different components that could be reclaimed, effectively meaning that the components identified for resale by the losing companies will be recycled rather than reused.

Perceived architectural limitations

According to Bert Albers, manager of sustainability and architect in the RVB, designing with reclaimed components limits design possibilities. Therefore, RVB considers the lack of architectural freedom a deal breaker, because of their high architectural ambitions. Their ambitions for circular demolition do not get the same priority as e.g. architectural freedom. This barrier is not unique to RVB and conversations with representatives from Erasmus MC have suggested that similar reservations would show up within their organisation if the practical limitations could be solved. Similar to quality concerns this barrier is a perceived barrier and requires a behavioural change to overcome. Reclaimed components can be used in outstanding architecture if both client and architect are willing to do so.

Preference for recycling

According to Bert Albers the reusability of certain components is highly theoretical. As an example, he gives a piece of balustrade made out of stainless steel and glass for the specific dimensions of the current building. Finding a reuse case for this specific component would take considerable effort, while both materials that make up the component are easily recyclable.

Opportunities

Since the project described in this case is a pilot with the explicit goal of identifying opportunities many opportunities have been identified, but fewer have been utilised.

Taken Opportunities

The integration of circular demolition as a criterion in the tender, which led to cost savings on the demolition as well as a successful pilot.

Identified Opportunities

Selling components under own management
The first opportunity identified by the RVB is a fundamentally different model than the model used in the circular demolition pilot. Selling components sourced from buildings under their own management would give more control to the RVB and keep the profits in house. The domeinen onroerende zaken who handle goods seized from people with a tax backlog have an auction website where the seized goods are sold. Something akin to this would be good for reclaimed components (B. Albers,

personal communication, November 17, 2018). However, there would be a limit on size since the storage requirements would be enormous. An alternative proposed by Bert Albers is in situ listing of building components. This way you minimise the need for storage by only disassembling the components that have already been sold. In addition to the size limit the inhouse experience needed for such an undertaking would be substantial.

Potential profits

Even though the mass percentage of reuse remains low for this pilot the prospective profit proved to be a considerable share of the total revenue. It was estimated that in case of demand for all reclaimed it would account for two thirds of the profit. Even though the components that could be reclaimed for reuse only accounted for 3.5% of the total mass of all materials.

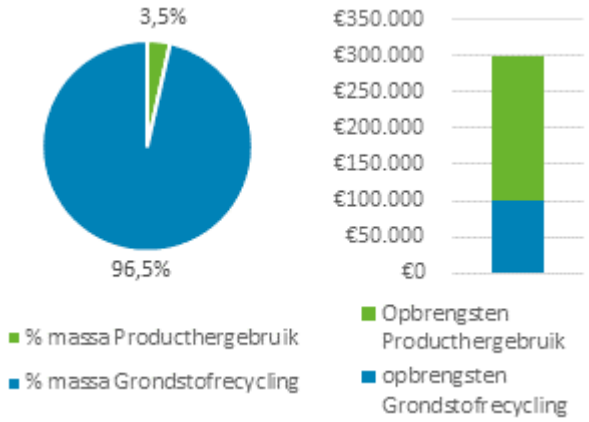

Figure 5.16: Prospective profit (report Buro Boot).

Differences between deconstruction companies Bert Albers put a lot of weight on the fact that the offers they received from the demolition companies that participated in the tender differed vastly. It is his opinion that this signifies unrealised reuse potential, since all demolition companies only offer to take back what they believe they can resell. In his words the different demolition companies that participated in the tender complemented each other almost perfectly in the different components they selected for reuse. This difference is due to the different supply chain partners of the companies.

Portfolio mining

The ambition to find a new use for new components within the portfolio managed by RVB has been voiced by different actors on several occasions but is not an official goal of the agency. The biggest challenge with this proposition is the fact that limiting the market makes matching supply and demand more difficult and is therefore likely to require more storage, but since the RVB is the largest internal market in the country this is a realistic opportunity. Currently an option for the reuse of components has been identified in the shape of a standard building interior that is used by RVB to quickly make buildings usable (B. Albers, personal communication, November 17, 2018). The temporary nature of this use case reveals the prejudice against used components present within the agency. Within the RVB there is currently no communication about the materials and components in buildings that will be demolished or refurbished with people working on construction projects. A more integrated way of thinking about the portfolio as a whole would open up possibilities for portfolio mining.

Concluding Comments

The Central Government Real Estate Agency has considerable experience with taking the lead in developments and is a forward-looking organisation in general. In the case of component reuse this translates into two projects: circular demolition of redundant buildings and material passports for new and refurbished buildings. Thus far there is not a strong link between the two projects potentially leaving opportunities untapped.

The discrepancies between the bids received revealed that substantial gains in component reuse can be made in since the received offers complement which materials are reclaimed almost perfectly. The tender in this project was a short tender with reuse as an award criterion rather than a demand. This did not invite the demolition companies participating in the tender to look outside of their regular network. If reuse would have been a demand, a higher percentage of reuse would have been possible. But to make such demands in the tender the RVB would require more in-house knowledge about the possibilities for reuse of different components. If reuse of the components for which RVB knows reuse to be feasible is a demand, the need for making reusability measurable for the tender disappears thereby simplifying the tender.

5.1.5 Erasmus MC

Figure 5.17: Image used at symposium on circular demolition at Erasmus MC (Windhorst, 2016)

Erasmus MC is one of the leading university hospitals in the Netherlands. Between 2009 and 2018 they are realising a master plan that will result in a single modern building complex, rather than the three separate hospital buildings that they currently occupy. To achieve this, a new building will be build and two obsolete buildings will be demolished. Since Erasmus MC is first and foremost a hospital, the main task of facility management is to keep the hospital buildings running during the project. Erasmus MC has a strong philosophy of doing what is best for the community. Facility management has interpreted this by trying to minimise waste and trying to find new uses for many of the components extracted from the buildings that will be demolished.

Business model

The business model of Erasmus MC is not focussed on construction. According to Andreas de Heij, project manager of the demolition project, the primary objective of Erasmus MC is to offer health care. In other words, for every euro that comes in the maximum amount of care should be given (A. de Heij, personal communication, November 20, 2017). Even so, the buildings occupied by the hospital are of vital importance for its daily activities and keeping the facilities adequate and up-to-date is an important activity for Erasmus MC and they instated an internal real estate division.

Role in the project

Erasmus MC is the building owner and client in this construction and demolition project. Their ambitions with regards to (social) sustainability are what is driving the circular demolition project. In their role as client they have written a tender in which circularity is an important criterium for being awarded the job.

Strategies

The Erasmus MC has teamed up with Madaster to set up digital material passports. Madaster offers the platform for this but Madasters approach differs from that of EPEA, who aided RVB in their pilot. The material passport platform built by Madaster facilitates the storage of information on building components and materials but does not offer guidance on the level of detail and amount of information that will need to be stored for it to be useful. This is where the experience of the selected demolition company is of great importance. The strategy is to select the demolition company that prioritises disassembly over demolition and has sufficient experience.

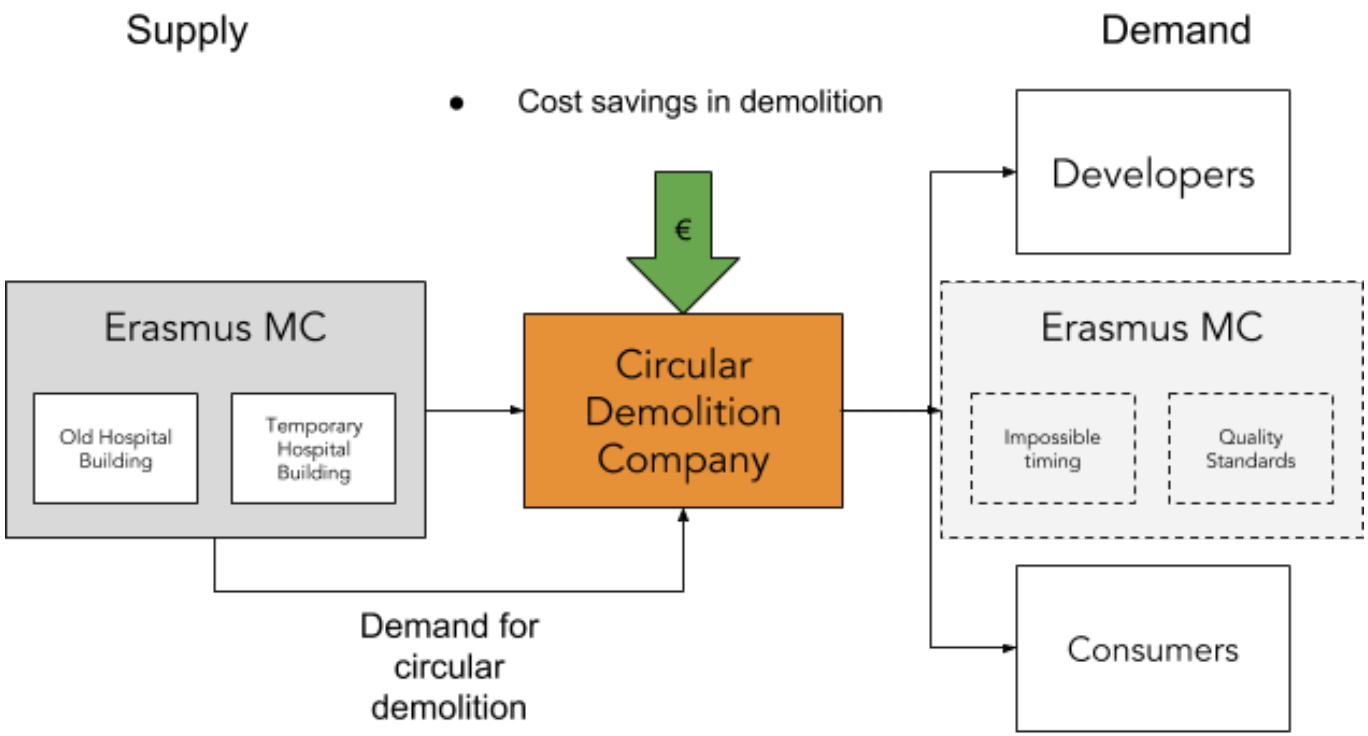

Figure 5.18: Role in the project of Erasmus MC

Risks

The risks that have been identified have been addressed in the tender and are described in the 'tender' section below. However, the way in which they were addressed in the tender, leaves the possibility open that a demolition company will be selected that has a very low circular ambition.

Subsidies

Erasmus MC does not collect any subsidies specifically for the implementation of circular demolition but has received a considerable contribution of 251 million euros for the construction project as a whole (Erasmus MC, 2016).

Overview of the project

The circular demolition of the redundant hospital buildings is part of the larger project in which Erasmus MC is realising a building complex. The larger project consists of two tranches: tranche I, or the construction phase which will be finalised in 2018 ('Erasmus MC Tender Document Tranche II', 2017); and tranche 2, the demolition phase which starts after the last building realised in tranche 1 is be taken in use. Tranche II will run from 2018 to 2022 ('Erasmus MC : Programma Tranche II', n.d.).

The new building of Erasmus MC will be fully finished before demolition of the old buildings begins. This is a necessity because the space in the buildings that are to be demolished will be in use until completion of the new building.

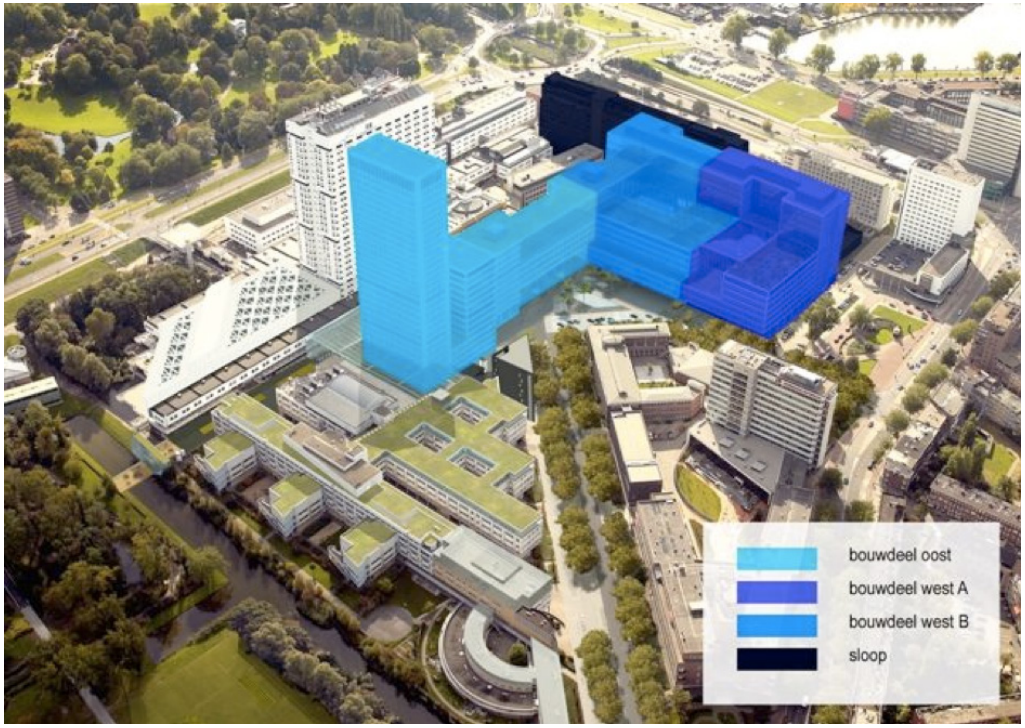

Figure 5.19: Different phases of the Erasmus MC renewal project ('Erasmus MC : Programma Tranche II', n.d.).

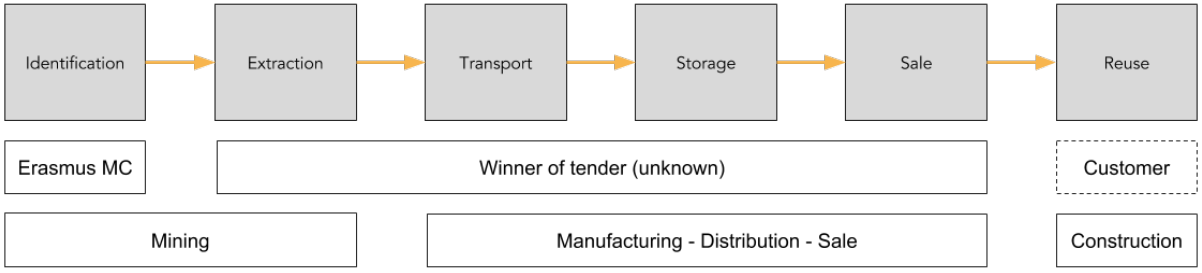

Figure 5.20: The place of Erasmus MC in the supply chain of the components to be reclaimed.

Material Passport Pilot

The pilot with material passports is important for the development of new knowledge linking material passports to circular demolition. In contrast to RVB where the material passport pilot was separate from the circular demolition pilot, Erasmus MC combines to similar pilots in one project.

Process

- Establishing ambitions

When the team of Erasmus MC embarked upon the journey of the circular demolition of their old buildings there was not much more than an ambition. In a search for possible ways in which to realise their ambitions

- Exploring possibilities

The exploration of possibilities for the circular demolition was kicked off by a round of lectures from speakers with backgrounds in architecture, demolition, and academics. The lecturese were followed by a brainstorm session to gather ideas from experts and students. These sessions were part of a full day seminar on circular demolition hosted by Erasmus MC.

- Tender process

After the symposium the gathered knowledge was translated into concrete goals that would become part of the tender brief.

Tender

The demolition of the redundant buildings has been divided into two phases that were tendered separately. The first phase consists of the demolition of a fairly new building that was erected 15 years ago as a temporary expansion to the hospital. The second phase consists of the demolition of the old Dijkzigt building, a building that was delivered in 1961.

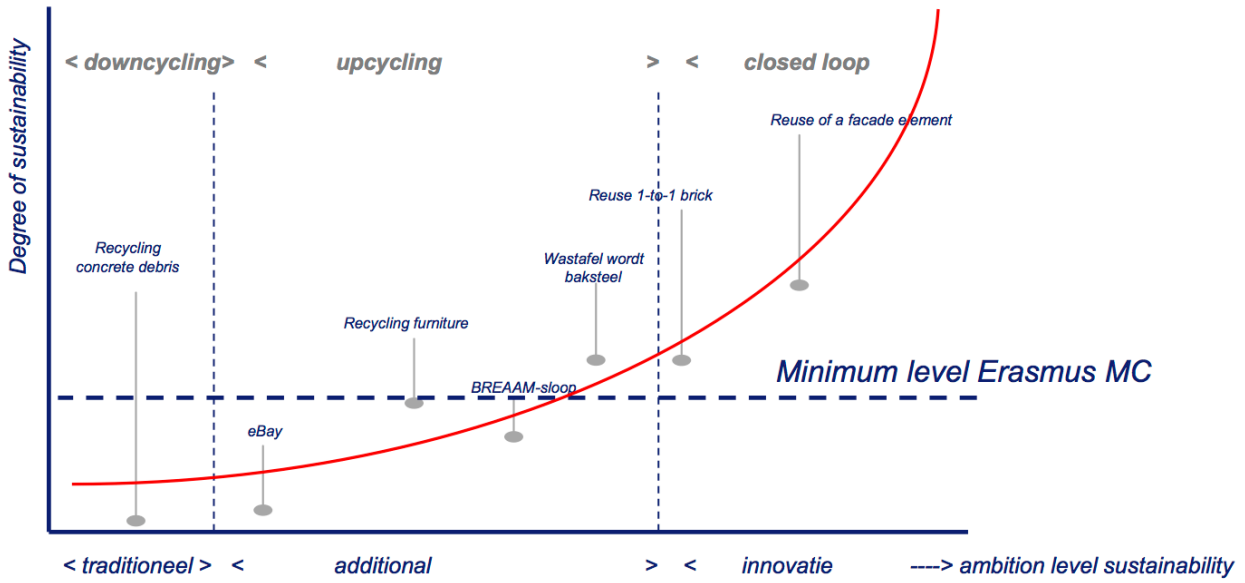

Figure 5.21: Ambition for circular demolition (slide symposium on circular demolition at Erasmus MC).

The ambitions for circular demolition are different for the two phases. These ambitions are based on the nature of the buildings that are demolished. For the modern building that will be demolished in phase 1 the tender allocates a considerable share of the points to circular demolition (T.M. van Iersel, personal communication, April 12, 2018).

The circular ambitions for phase 2 are high as well, accounting for 10 out of 80 points in the award criteria of the tender, but lower that the circular ambitions for phase 1. Because of the age of the Dijkzigt building it is expected to contain fewer components that can be reclaimed feasibly (T.M. van Iersel, personal communication, April 12, 2018).

Supply chain

Since the tender of this project has not reached its end yet, there is no certainty about the way it will be set up. Erasmus MC remains the owner of the buildings and materials in the mining phase, Madaster was commissioned to create a material passport for the building that will be demolished in phase 1.

Main Drivers

Company policy of Erasmus MC is to provide maximum value for the direct environment c.q. the city of Rotterdam with minimal environmental impact. The team responsible for part of the renovation plans, chose to interpret this policy as a wish for making components resulting from the demolition of their old buildings benefit society.

Social role in society

The primary objective of Erasmus MC is to offer health care. This is the setting from which the demolition needs to be approached. Since the demolition of a building costs money, at the cost of providing care, one driver is cost minimisation. From this starting point the main drivers for the demolition assignment can be ordered as follows:

1. Safety
2. Cost savings
3. Social role in society

The third point in this list is especially important with regards to the city of Rotterdam. Since the hospital considers the Dijkzicht building part of regional heritage all initiatives trying to preserve components for uses within the city could count on support. Bottom-up actors in the organisation have added the two objectives:

1. Circular demolition
2. Breaking even or making a profit on the circular demolition

The human factor

The principal driver for circular demolition is the personal drive of the demolition project team. There were no incentives from higher up with regards to sustainable ambitions. In spite of this the project team, led by van Iersel, decided to make circular demolition part of the project. Even though this was not asked for by the board, it does fit with the corporate policy of Erasmus MC and their societal goals. As long as the safety and costs are similar to a traditional demolition the project team was given green light to follow their ambitions.

Main Barriers

The project is currently in the tender phase, therefore no barriers in the later stages of the project can be identified yet. However, in their pursuit of the circular demolition of the Dijkzigt hospital and surrounding buildings some barriers have already been encountered.

Health and safety

The presence of asbestos makes the reuse of some components unfeasible, this is illustrated by the different priorities assigned to reuse between phase 1 and phase 2. Since the buildings demolished in phase 1 are only fifteen years old asbestos is not present in these buildings allowing for a higher ambition for reuse.

Lack of experience

There are no companies that have experience with circular demolition at the scale of Erasmus MC. This became very clear after the initial symposium hosted by Erasmus MC to kick off the circular demolition project (T.M. van Iersel, personal communication, April 12, 2018). Since the demolition project will be undertaken while the surrounding buildings are still in use experience in sensitive projects of similar size is important to Erasmus MC and this has been given considerable weight in the tender. The downside of this approach is that it creates a barrier to entry for the most experienced circular demolition companies.

Opportunities

Since this project is still on its way to be realised there are interesting opportunities to be identified. Some identified opportunities have been dismissed early in the project but could offer valuable insights. Other opportunities have been made part of the tender document and applicants are encouraged to find more opportunities.

Taken Opportunities

Demands for circular demolition have been included in the tender. The original ambitions for circular demolition have been included in one single award criteria, with considerable weight, regarding sustainability. Component reuse is preferred over recycling and awarded with extra points.

Identified Opportunities

Both the opportunities of reuse within their own buildings (portfolio mining) and local reuse at a city level have been identified. Neither of these could be utilised however, since at the moment of demolition no demand has been found. Because Erasmus MC is a hospital and does not want to stray too far from its core business an external party would need to get involved to match supply and demand between unknown parties and take care of temporary storage.

Concluding Comments

The interesting thing in this case is how an organisation without much experience in the construction sector decides that their planned demolition projects should be carried out in a circular manner. The initial enthusiasm coming from one person was picked up by the rest of the team and remains throughout the project preparations and circular demolition is used as one of the assessment criteria in the tender.

The journey taken from the initial idea to the tender reveals how young the field of circular demolition is and how little experience exists for projects of this size. No companies with experience in circular demolition had experience with demolition projects as big as the demolition of Dijkzicht while Erasmus keeps running. On the other side no companies with experience in projects of this magnitude had

The mere existence of this case underlines the importance of behavioural drivers. No plans to demolish the old Erasmus MC buildings in a circular manner were initiated because of company policy, but solely originate from the real estate team. The adoption of the ideas by the board does result from the corporate policy and its emphasis on contributing to society.

5.2 Cross Case Analysis

In this section of the report a closer look will be given to the cases that have been described in section 5.1. First topics for which observations have been made in multiple cases are discussed. Subsequently a comparison between similar cases is made starting with Bouwcarrousel and Rotor DC in subsection 5.2.1 followed by RVB and Erasmus MC in subsection 5.2.2.

The five cases described in the previous chapter are similar in some ways, but different in many others. These differences make them interesting to study, while the similarities are useful to identify trends.

Even though both the case of the Government Real Estate Agency and Erasmus MC are largely about a single project. The fact that RVB is a company that will do many more of such projects in the future while Erasmus MC is unlikely to do similar projects in the future, has considerable influence on their approaches (table 5.2).

The material flow of a building start at the mining of the raw materials needed for the manufacturing of building components. Traditionally after a building has been built, used, and eventually demolished the resulting material streams end up in open-loop recycling or as waste.

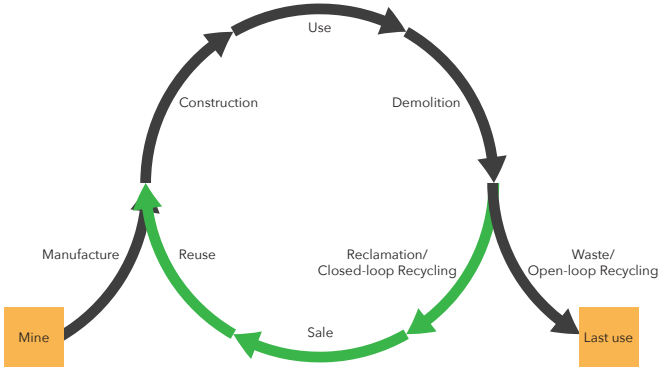

Figure 5.22: Supply Chain of Components.

The cases analysed in this study are situated at different places in the circular supply chain. The focus of the research starts at the reclamation phase, but some cases extend into the reuse phase. Even though none of the positions in the supply chain of the different cases fully overlap, a clear separation can be made between facilitator cases and client cases.

5.2.1 Client Cases

For the facilitator cases their role is in the supply chain is clear, as are the questions they can help answer. The organisations of the two client cases are still unsure about their own role and are exploring many different avenues of being involved in circular economy. Even though RVB as an organisation is significantly bigger than Erasmus MC, the two organisations fulfil a similar role in their respective case, making them suitable candidates for a one-on-one comparison. Both organisations have demolition and construction projects running simultaneously and both organisations commissioned the projects by means of a tender that included circular demolition requirements. The big difference between the two is that all the smaller projects of Erasmus MC combined are in fact one project that will end when all the sub-projects have finished. The government real estate agency on the other hand, is an organisation that exists to manage real estate and construction projects. The main difference between the two cases is that Erasmus MC is both owner and user of

Van Liempd	**Bouwcarrousel**	**Rotor DC**
Facilitator (circular demolition)	Facilitator (circular demolition)	Facilitator (circular demolition/consultancy)
	Rijksvastgoedbedrijf	**Erasmus MC**
	Company	Project

Table 5.1: The cases and their

the building, while in the case of the government real estate agency, the agency is the owner, but the user will be a ministry or another government body. This leads to a different equitation for the operating costs of a building. For an owner-operator, cost savings made by increasing the efficiency of employee tasks are important to their bottom line. Whereas for an owner it could make sense to use cheaper components since the costs for decreased efficiency of the user are not part of their bottom line. For the cases of this study this difference is not as black and white, since the government real estate agency is connected to its building users. Both organisations have shown their eagerness to find innovative methods and willingness to engage by hosting brainstorm sessions and using the results in their tenders. Even though both organisations have toyed with the idea of reusing reclaimed components within their own building portfolio, both have thus far failed to do so. The reasons for this seem to be different. Erasmus MC has come to the conclusion that their stock is too small to make reuse within their stock feasible. I would argue that while size of the stock is an important variable, the importance of planning cannot be disregarded. The new building of Erasmus MC will be fully finished before demolition of the old buildings begins. This is a necessity because the space in the buildings that are to be demolished will be in use until completion of the new building. RVB does not share these problems and even has other incentives, that have been discussed before, that would make portfolio mining preferable over other reuse alternatives. Their ambitions for circular demolition do not get the same priority as e.g. architectural freedom. This barrier is not unique to RVB and conversations with representatives from Erasmus MC have suggested that similar reservations would show up within their organisation if the practical limitations could be solved. Informal interviews with employees from both organisations revealed some hesitations towards the use of reclaimed materials in their new buildings. Reasons mentioned for this hesitation are high quality standards, architectural freedom, and supply constraints. The presence of these hesitations in companies that are actively working to reclaim as many components as possible from the other end of the supply is startling.

Erasmus MC, being a hospital has somewhat stricter requirements for their real estate than companies in other fields and their hesitation towards reusing components is understandable. Unfortunately, the attempts to find new internal uses for the reclaimed components proved to be impossible for logistical reasons and were stopped before the regulatory issues became a problem. This would however be an interesting avenue for further research. This inability to use reclaimed components by two organisations that are at the forefront of circular demolition suggests the need for a shift in culture at the demand site, similar to the shift in culture that is already taking place in the supply side. This need for changes on the demand side has been articulated by every single expert both formally and informally.

Both client cases are active in the same links of the supply chain. Ideally these cases would extend their presence to include the 'reuse' link, but this comes with a different set of challenges than that of a circular demolition. Both organisations have demolition and construction projects running simultaneously and both organisations commissioned the projects by means of a tender that included circular demolition requirements. The big difference between the two is that all the smaller projects of Erasmus MC combined are in fact one project that will end when all the sub-projects have finished. The government real estate agency on the other hand, is an organisation that exists to manage real estate and construction projects.

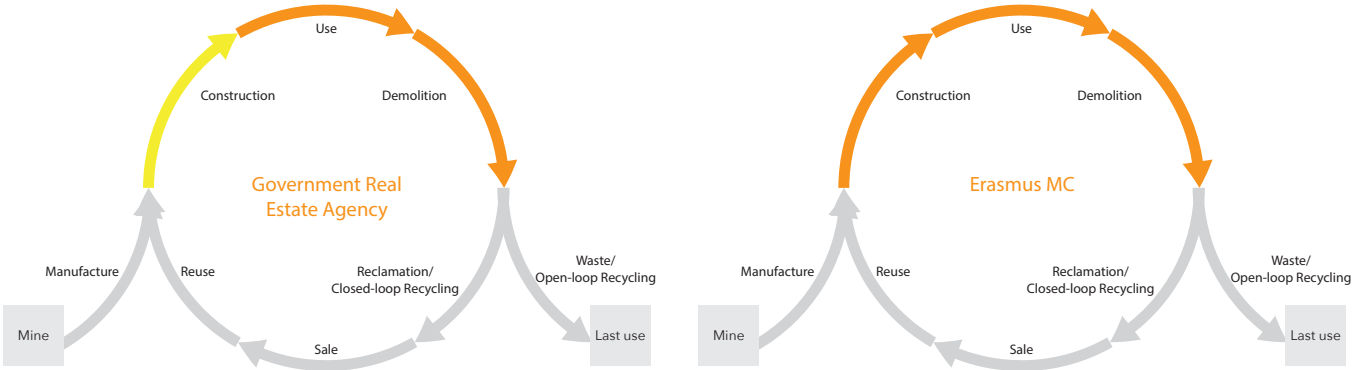

Figure 5.23: Places in the supply chain where the client cases are active.

5.2.2 Facilitator Cases

Bouwcarrousel, Rotor DC, and Van Liempd occupy the same position in the supply chain. Even so, their approaches differ significantly in a number of ways. Both Bouwcarrousel and Rotor DC present themselves as circular demolition companies, but they do more than demolition alone. Van Liempd has positioned itself as more of a traditional demolition company and competes for the same projects, even though they only do circular demolitions. All three companies are involved in the process from the moment of identification of reclaimable components to the actual sale of those components. Their approaches to identification differ: Rotor DC selects components on the condition that they have a high likelihood of being resold; Bouwcarrousel uses the reclaimability as the main criterion and takes in everything that can be disassembled; Van Liempd takes the same approach as Rotor DC when making an offer, but often decides to take a chance on components for which resale is less certain.

This difference translates into three different strategies for selecting the components that are to be reclaimed. The first strategy, as used by Bouwcarrousel and van Liempd, entails the demolition and intake of all components by the demolition company. In this case sorting and selection of the components is to be done partly offsite. In the second strategy, as used by Rotor DC, the demolition company only selects the components it deems valuable for transport to their premises. This requires the sorting and selection of components to be done fully onsite. Both strategies have their strengths and weaknesses. The strength of the first strategy lies in the seamless process created for the client. Everything is transported offsite by one company, thereby moving the extra complexity to the deconstruction company. This strategy is attractive for the client since extra time and costs on the deconstruction side can be avoided. The weakness of this strategy is that virtually all of the risk is concentrated on the deconstruction company. Van Liempd manages this risk by transferring ownership of the components to a sister company after they have been reclaimed. The second strategy avoids most risk for the deconstruction company by selecting the components that will be reclaimed onsite and only transporting the selected components to the premises of the deconstruction company. There is a weakness to this strategy as well, in that it relies on the client to make extra time in the demolition schedule. Risks are mainly carried by the client, while benefits are mainly concentrated at the deconstruction company.

While both strategies have their merits, it should be noted that these are two extremes of a spectrum, making both the strengths and the weaknesses more pronounced. The fact that these cases are situated at opposite ends of the spectrum is what makes them such valuable cases for analysis.

The positions in the supply chain of Rotor DC, Bouwcarrousel, and Van Liempd are all built around the ‘reclamation’ link. Even so, their approaches from there differ significantly in a number of ways. Both Bouwcarrousel and Rotor DC present themselves as circular demolition companies, but they do more than demolition alone. Van Liempd has positioned itself as more of a traditional demolition company and competes with them for projects, even though they only do circular demolitions.

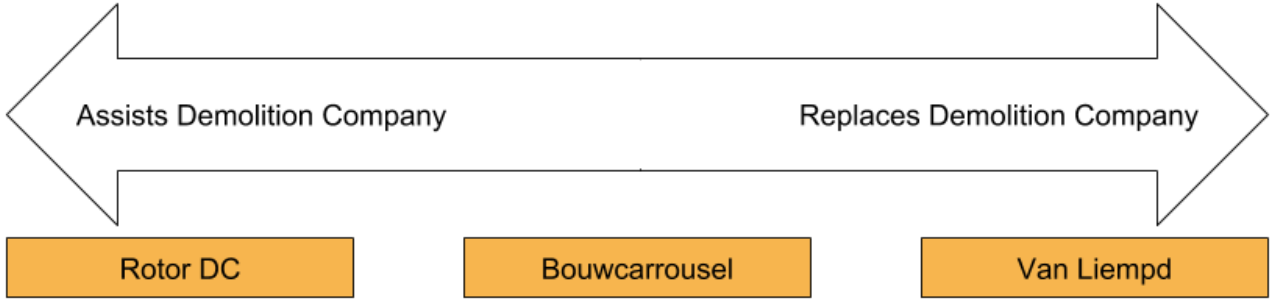

Figure 5.24: Extent to which the circular demolition companies can replace a traditional demolition company.

The differences between the where the three facilitator cases are active in the chain are much bigger than those of the client cases (fig. 5.23). All three companies are involved in the process from the moment of identification of reclaimable components to the actual sale of those components. The ‘reuse’ link is underrepresented in these cases as well. Bouwcarrousel had some activities in the ‘reuse’ and ‘construction’ links, but these can largely be regarded as side projects. Rotor DC purely works in the links that are not part of traditional demolition processes, whereas Bouwcarrousel treads into the domain of traditional demolition companies and Van Liempd fully replaces them.

Where Van Liempd, and to a lesser extend Bouwcarrousel are capable of replacing a traditional demolition companies and also takes care of non-reusable materials, Rotor DC only reclaims the selected components after which a different company comes in for the remainder of the building (fig. 5.25). This difference in approach leads to a higher percentage of resold components for Rotor DC, since they only take components they deem sellable in the first place. While this business model is working for the moment it does not seem sustainable in the long term. Much like the build-up of materials was unsustainable for Bouwcarrousel, the stripping of buildings for materials without offering compensation to the owner seems to have an expiration date. Van Liempd solves prevents the build-up of components by working with recycling companies that take care of their excess materials.

All three companies have their own challenges but have also unknowingly solved some of each other’s problems. Companies that apply the first strategy can apply the focus that Rotor DC puts on the quality of materials when selecting components for resale. Since Bouwcarrousel already transports non-reusable materials to recycling, the same could be done for components that can be reused but are unlikely to have demand. Similarly, Rotor DC could take some strengths from the first strategy and expand the services it offers, or partner with other companies to offer more services. On the other side of the spectrum they could limit their own activities to the re-manufacture and re-sale side of components leaving the deconstruction to a dedicated company.

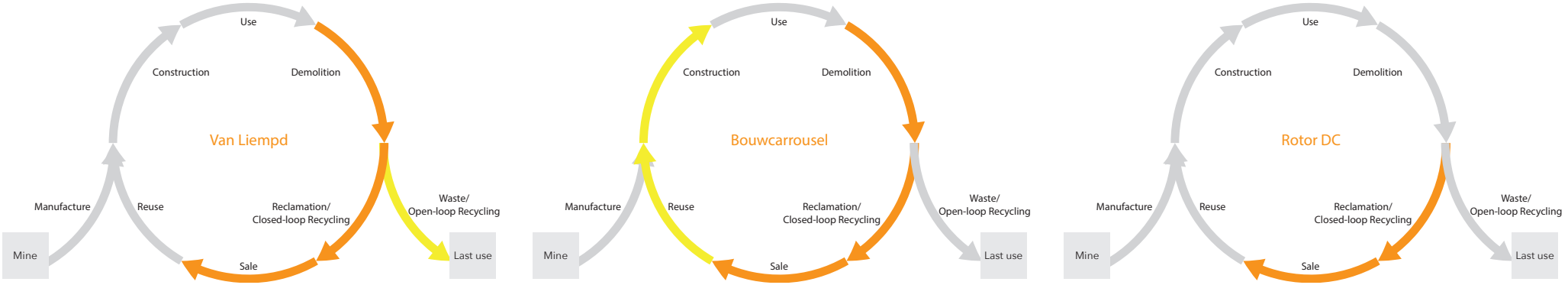

Figure 5.25: Places in the supply chain where the facilitator cases are active.

Material Flows

Using Sankey diagrams to visualise the cases reveals how the differences of the three approaches in the facilitator cases manifest in the material flows. All three companies have the goal of facilitating circular demolition but result in vastly different material flows. Their relationship with traditional demolition companies also differs considerably (fig. 5.25), spanning the spectrum from minor assistance up to full replacement. In this order the three cases are given a closer look. The material flow diagrams are based on approximations made by the interviewees from the different cases, with regards to the share of components that is reused compared to the total building weight.

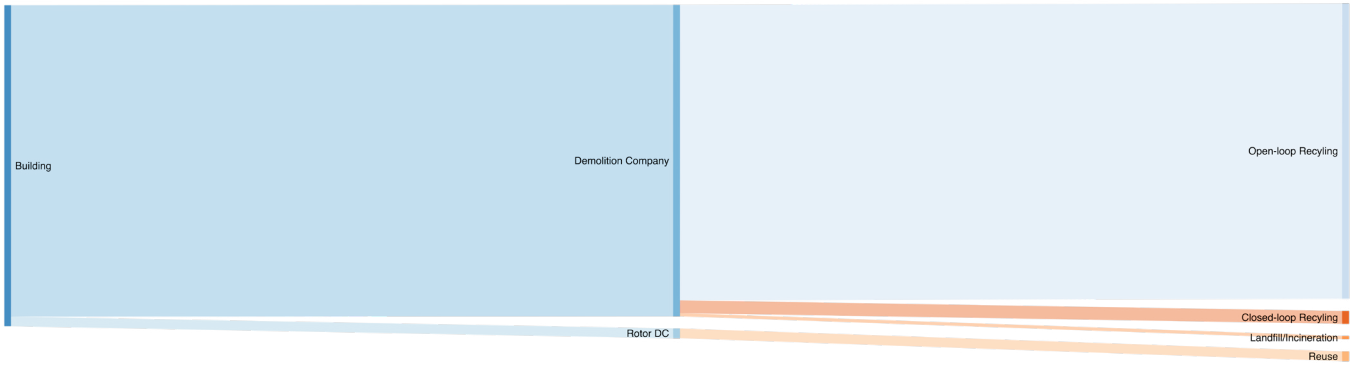

Figure 5.26: Material Flows of Rotor DC (approximation)

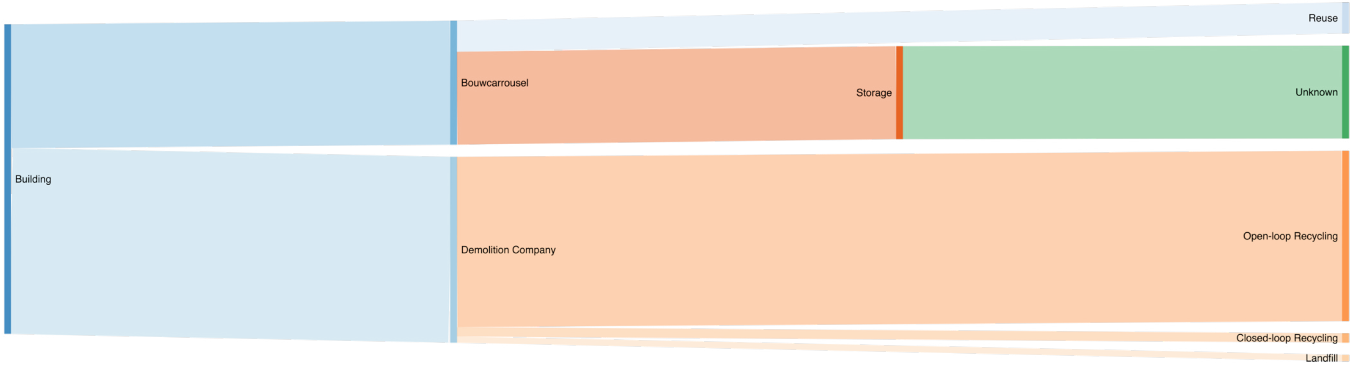

Figure 5.27: Material Flows of Bouwcarrousel (approximation)

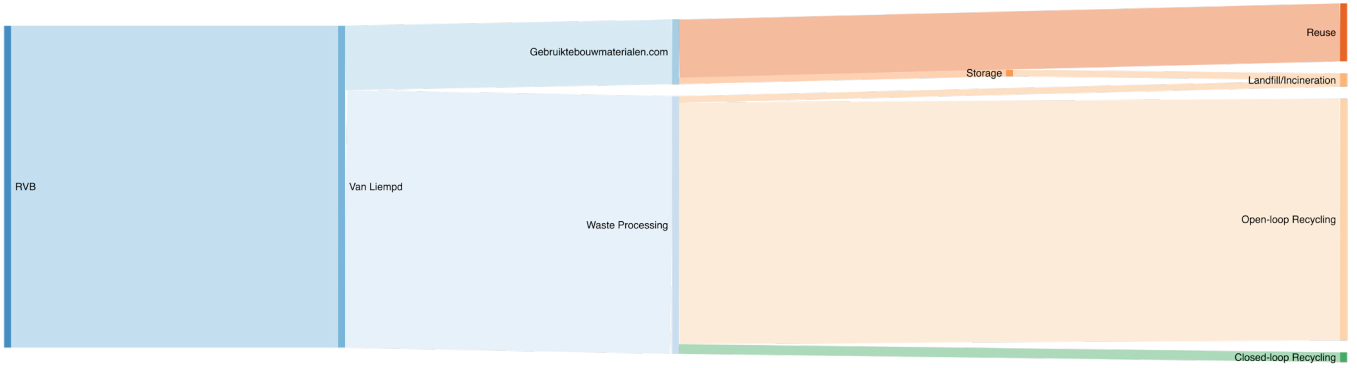

Figure 5.28: Material Flows of Van Liempd (approximation)

Rotor DC

Rotor DC sells nearly everything that they reclaim. This translates into very strict criteria for reclamation resulting in 95% to 97% of the building that is demolished by a traditional demolition company and will follow the established path for disposing of construction and demolition waste. Comparing this to the circle diagram (fig. 5.25), Rotor DC only provides services that are not part of the traditional supply chain, focussing instead on filling in the missing links.

Bouwcarrousel

The material flows of Bouwcarrousel (fig. 5.27) are very different from those of Rotor DC. Where the flows tapped by Rotor DC barely register compared to the total flows of the demolition, the dent made by Bouwcarrousel is much bigger. It has to be acknowledged however that this strategy has considerable disadvantages. The burden of selling the reclaimed components is carried fully by Bouwcarrousel while a discount for not having to pay waste processing costs has already been passed on to the client at the time of demolition. The unknow share can be explained due to the fact that the occurrences after bankruptcy are unknown to this study. It is likely however that the stock at the time of bankruptcy has been auctioned off with a small part going to reuse, while the remainder would have been processed as construction and demolition waste.

Van Liempd

In the first link in which van Liempd is active they take 100% of the material flow, this is then divided in two streams. Components suitable for reuse are transferred to gebruikteboumateralen.com and the remainder of construction and demolition waste is sent to an external company for processing. The share of components designated for reuse is similar to that of Bouwcarrousel, but the larger network and additional remanufacturing facilities cause a larger share to be sold.

Winning Strategy

As a full strategy Van Liempd holds the most promise for long term viability, but that does not mean that the insights gained from the two other facilitator cases hold no value. While the business model of Van Liempd is the most sensible from a business point of view, the methods of Bouwcarrousel and Rotor DC help to push the envelope of component reuse. Where Van Liempd, and to a lesser extend Bouwcarrousel are capable of replacing a traditional demolition companies and also takes care of non-reusable materials, Rotor DC only reclaims the selected components after which a different company comes in for the remainder of the building (fig. 5.25). This difference in approach leads to a higher percentage of resold components for Rotor DC, since they only take components they deem sellable in the first place. While this business model is working for the moment it does not seem sustainable in the long term. Much like the build-up of materials was unsustainable for Bouwcarrousel, the stripping of buildings for materials without offering compensation to the owner seems to have an expiration date. Van Liempd solves prevents the build-up of components by working with recycling companies that take care of their excess materials.

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Part II - Drivers and Barriers for Circular Demolition and Component Reuse

In this chapter the cases that have been described and compared in Part I of the findings are further analysed in tandem with relevant literature and with the help of a research framework. The goal of this analysis is the identification of drivers and barriers for circular demolition and the utilisation of reclaimed components in the construction industry. The results of this analysis will further be used to identify opportunities to integrate component reuse in the supply chain of a construction or demolition project. The individual cases help to shed light on the drivers and barriers experienced in each one of them. The drivers and barriers as represented in this chapter are specific to the analysed projects and may or may not be generalisable.

The relevancy of the identified drivers and barriers can be increased by taking an extra step in the analysis to come to a more general understanding. For this purpose, a framework has been selected and described to ensure a complete and objective analysis of the identified drivers, barriers (chapter 4).

As discussed in the chapter on methodology, Pomponi & Moncaster (2016) propose a framework that can be used to aid research into circular economy in the built environment.

A key component of this framework is the inclusion of societal and behavioural elements, which are often omitted in favour of technical elements.

The multi-disciplinary approach of the framework ensures that the cases are analysed from all angles that are relevant to circular building and make it perfectly suitable for the analysis of the drivers, barriers, and opportunities present in this multiple case study. However, the aims of this study are not limited to the identification of drivers and barriers. In addition, an attempt will be made to find opportunities to lift identified barriers and utilise the drivers. In order to do this, elements from policy analysis (Enserink et al., 2010) , have been added to the framework of Pomponi & Moncaster (2016).

			Van Liempd	Bouwcarrousel	RotorDC	RVB	ErasmusMC	Notes
Drivers	Governmental	*Zero waste goals*			I	I		
		Subsidies for cirular initiatives			I			Belgium
	Economic	*Short term profit (cost savings)*	*I*	S		I	I	
		Long term profit (experience/sale)		I		I		
	Environmental	*Resource efficiency*	*I*	I	I	SE	SE	
		Taking care of the environment	*S*	S	S	P	SE	While 'environment' is a very broad definition, this reason is mentioned universally as a driver.
	Behavioural	*Company policy*			I	I	SE	
		The human factor		I	W		I	
		Demand for circular demolition	*I*	I	I	W	O	RVB and ErasmusMC show demand for circular demolition
	Societal	*Corporate image*				I	I	100% of the corporations
		Role in society				S	I	
	Technological	*Online sales platform*	*W*	W	W	W		Facilitator rather than driver

Table 6.1: Drivers linked to cases.

6.1 What are the Drivers for Component Reuse?

This section details the drivers found in cases to answer the research question: What can current projects teach about the drivers for integrating reclaimed components into new buildings in the Benelux and how do these drivers compare to prior research. First the drivers encountered in the cases are shortly described after which they are placed in the analytical framework and further analysed in individual paragraphs.

Three drivers where encountered in all four of the case studies. Resource efficiency and environmental impact are two important drivers to initiate circular projects. Because of these two strong drivers there is a strong demand for circular demolition. Both of the cases in which circular demolition is not the primary business goal have instated company policies about waste minimisation and circular ambitions. The national governments have instated zero waste goals, driving companies to adapt these on time. Within the four cases only one direct subsidy was encountered. The subsidy in question was unique to the case and is not a universal one instated to promote component reuse. Lastly profit is a goal shared by all four of the cases albeit in different timeframes. The identified drivers and their sources are listed in Table 5.1.

6.1.1 Governmental Drivers

Subsidies and tax breaks

While none of the analysed cases receive direct subsidies, most of them receive tax exemptions of some kind. Currently this is an important driver since the extra costs for a slower demolition process can be regained this way. In the case of RotorDC the costs for storage are lowered drastically since the warehouse is situated in a disused chocolate factory rented to them by the municipality of Brussels South for a fair price on the condition that they leave when a different purpose for the grounds is found. In discussing the barriers to steel reuse in construction, Roy Fishwick (Corbey, Cullen, Sansom, & Fishwick, 2016) highlighted the role that policy can play as current market prices for steel are so low that steel reuse is hardly economically viable. Additionally, he reported on lack of will at EU regulatory level that could be detrimental to steel reuse. For component reuse governmental drivers can be of similar importance.

Zero waste goals

The national government has ambitions to close material loops (Schut et al., 2016). The construction industry plays a big role in these ambitions. As a public institution, RVB follows the ambitions of the national government and their goal to cut CDW by 50% in 2030 and achieve a fully circular economy in 2050. This driver affects every entity with waste to dispose of but does not directly apply to newly built buildings.

Rob Gort stressed the inhibiting effect that the current tax system has on the practise of component reuse (R. Gort, personal communication, Mei 19, 2017). Since there is a tax on both labour and goods reclaimed components can struggle to compete with new components that have been produced in countries where the tax on labour is lower. The importance of tax breaks is confirmed by Adams (2016).

While it is true that taxation increases the price of reclaimed components, all three of the companies analysed for this study sell their components with value added tax included.

6.1.2 Economic Drivers

In an ideal case this scarcity would translate into expensive materials, the truth of the matter is however that most materials that can be reclaimed are not scarce enough for it to have any noticeable effect on the price. Nonetheless, all four studied cases have economic drivers at heart. Two distinct drivers have been identified.

Short term profit

Three of the four studied cases have short term profit as a driver for their current activities that involve component reuse. Even though material scarcity is not a driver in itself for most materials that are reclaimed from buildings, there are com-

ponents in buildings that maintain their value. To maximise the immediate profit, or cost savings, all three of the companies have decided to limit their ambitions for component reuse to components that they deem valuable or easy to sell. This is usually achieved by a first phase of deconstruction, followed by a traditional demolition for the remainder of the building. This strategy raises the question whether the net effect is positive. After all cherry-picking valuable components could make the rest of the demolition less profitable. But in the current market the exposure and knowledge gained for circular demolition make this a useful endeavour.

Long term profit

Two of the four case studies have long term profit as a driver. They expect the market for reused components to grow and treat current projects as a way to gain experience. Bouwcarrousel went bankrupt before the market had sufficiently grown to satisfy the long-term profit goals. The government real estate agency is aims to integrate circular principles into all their projects and expects them to be profitable. Currently however they treat the circular demolition projects as pilots to learn from for future projects.

6.1.3 Environmental Drivers

Environmental drivers are of great importance in the bigger shift towards a circular economy in the construction industry. However, at the micro-level of circular demolition these drivers are largely indirect and manifest mainly through behavioural and governmental drivers. E.g. 'The European Commission, national and regional administrations are developing circular economy policies to bring benefits to the environment and the economy' (Adams et al., 2017). Nonetheless, two environmental drivers have been found in the cases. In each of the four cases the promotion efficient use of resources has been found as an important driver, as well as taking care of the environment.

6.1.4 Behavioural Drivers

Behavioural drivers are drivers that are the direct result of changing perceptions by stakeholders. that a shift in behaviour has happened or is happening.

The human factor

A common theme that can be found in all four of the cases is the reliance on human initiative. In many cases the original spark does not come from economic incentives but from a person or group of people with a passion for component reuse. This is true for two of the three circular demolition companies that were founded first and foremost to prevent the waste of materials and preserve their embodied energy. Perhaps more surprisingly it is also the case in the circular demolition of Erasmus MC where the right person in the right place has proven to be the most principal driver for the circular demolition project.

Demand for circular demolition

Demand for circular demolition or deconstruction is growing. This demand stems from the unwillingness to let resources go to waste. This is a big shift in how construction and demolition waste was perceived prior and is strongly related to the environmental driver of not wasting resources. However, thus far demand for the reclaimed components has failed to keep up. This suggests that the change in behaviour manifests when materials and components are designated for demolition, but not while building new buildings.

6.2 What are the barriers obstructing component reuse?

Despite the drivers and opportunities discussed in the two previous sections, as well as the many initiatives that aim to facilitate component reuse, the fact remains that as of this moment there is no functioning market for reclaimed building components. This means that there are barriers that have yet to be overcome. In chapter 3.4 it was established that the primary barriers to component reuse are: the fact that current buildings have not been designed for reuse (Addis, 2012; A. R. Chini, 2005; Gorgolewski, 2008); the necessity to design with the reused components in mind (Addis, 2012; Gorgolewski, 2008); and difficulties with contractual and organisational structures (Gorgolewski, 2008). This chapter will answer the question: What can current projects teach about the barriers to integrating reclaimed components into new buildings? By extracting the barriers identified in the four cases and where necessary comparing those with barriers identified in prior research.

			Van Liempd	Bouwcarrousel	RotorDC	RVB	ErasmusMC	
Barriers	Governmental	*Tender Rules*	*I*		I	I		
		Unclear regulations		P		I	I	
	Economic	*Extra costs of demolition*		S				
		Time constraints for deconstruction					I	
		No demand for reclaimed components	*I*	I	P		I	RVB did not experience this because they outsourced the sale of components
		Price of transport and storage		P	P		SE	
		Matching supply and demand	*I*	I	I	I	SE	ErasmusMC main topic of the seminar
	Environmental	*Health risks*		S	I		I	
	Behavioural	*No demand for reclaimed components*	*I*	O	I	O	I	In there twice, this one is more about perception
		Perceived lower quality of reclaimed components	*I*	I	O	I	I	RotorDC acknowledges this by only focussing on the select components that do have demand
		Architectural freedom				I		Only explicitly mentioned by RVB
	Societal	*Traditional procurement methods*		I	I	I		
		Lack of experiece					I	
		Lack of transparancy				SE	I	Both RVB and ErasmusMC embarked on partnerships to improve this
	Technological	*Quality control*		I	I	I	I	
		Requires knowledge of materials in the design phase			I		I	
		Lack of supply chain integration		I			I	
		Extra complexity in supply chain			I	I	P	

Table 6.2: Barriers linked to cases.

Barriers encountered in all four cases emphasize the difficulty in matching supply and demand of reclaimed components. A lack of demand for many components is also a barrier encountered in all four cases. An interesting barrier that has been identified in all four of the cases is the perceived lower quality of reclaimed components. This barrier is that it has been encountered by the resellers but has also mentioned by the potential clients as a real barrier. One of the clients mentioned a lack of architectural freedom in addition to the lower quality. Difficulties of quality control on reclaimed components versus newly produced components where identified in all cases as a barrier. However, this barrier has been overcome or avoided in different ways. Price of transport and storage is something that comes up time and again and a difficult barrier to overcome. Even though it has been tried to overcome this barrier in different ways. The identified barriers and their sources are listed in Table 5.2.

6.2.1 Governmental Barriers

Tender rules

The requirement for tendering makes the sale of reclaimed components difficult in any projects involving public stakeholders. In the case of RVB an interested party had been found for the kitchen of the building that was going to be demolished but due to the necessity to write out a tender the sale of reclaimed components had to go through the winning demolition company without influ-

ence of RVB. Similarly, in the same project the different demolition companies competing for the tender identified different components that could be reclaimed, effectively meaning that the components identified for resale by the losing companies will be recycled rather than reused.

Liability

Because there are no regulations specifically for component reuse, projects involving it need to re-invent the wheel for many contracts. In many cases it is unclear who is liable in case of defective components or whether reclaimed components would satisfy general building regulations. As a result, many initiatives take the safe road and avoid risky components. Because of the uncertainty involved, Rotor DC for example, does not reclaim structural elements even though these often have a high economic value and are suitable for reuse. Liability is always an issue in the construction industry, therefore legislation for traditional materials has been in place for a long time. With reclaimed materials however, new questions arise; who is responsible if a secondary building component turns out to have hidden weaknesses, the demolition company, the middleman, the contractor of the new building?

To overcome this barrier complicated contracts, have to be in place for every construction project that utilises reclaimed materials or components. According to Lionel DeVlieger the creation and negotiation of these contracts poses a significant barrier for many projects (L. DeVlieger, personal communication, October 2, 2017). Instead this barrier is often circumvented by avoiding the reclamation of structural or even façade components.

6.2.2 Economic Barriers

Extra costs of demolition

According to Bouwcarrousel and Rotor DC circular demolition takes longer and requires more expensive labour than traditional demolition methods. This means that it is only economically viable if the extra costs can be recuperated by costs saved on waste disposal or profit from the resale of components. However, if the cost recuperating activities are factored in, the total price of a demolition project can lower than those of a traditional demolition (B. van Dinther, personal communication, April 18, 2018).

Time constraints for deconstruction

Projects with a short timeframe will have difficulty implementing slower methods even if the costs can be recovered. Whether this is a barrier is debatable, however, since disassembly is becoming more common than destructive demolition, even in cases were component reuse is not the goal. According to Barthel van Dinther, of Van Liempd circular demolition does not need to take extra time compared to other currently used demolition methods (B. van Dinther, personal communication, April 18, 2018).

Price of transport and storage

Storing components until they are sold requires extra transport. Where regular construction and demolition waste can be transported directly to the waste processor or recycling facility, components designated for reuse need to be transported to a storage facility, be stored, and after sale be transported again. This transport and storage of the reclaimed components is costly, meaning that the already slim margins on r hand building components need to account for these costs.

Limited demand for reclaimed components

Demand for the reclaimed components cannot be guaranteed. Two of the analysed cases directly identified this barrier and found demand for most components to be very low. According to Bouwcarrousel and Rotor DC the selection of components for which demand can be found requires experienced workers. Both Rotor DC and Bouwcarrousel use these experienced workers to identify the components that are likely to have demand.

At Bouwcarrousel it was observed that the biggest problem for demand was a lack of demand from professional customers. More than ten years later Van Liempd is struggling with the same problem (B. van Dinther, personal communication, April 18, 2018). This study strengthens this hypothesis by confirming that the two companies from the multiple case study have little interest in using reclaimed components in their new buildings.

Limited supply of reclaimed components

As much as the demand is limited, for large scale construction projects supply is also limited. Large scale construction projects often order components in bulk. This can often be challenging with reclaimed components, after all, if you want identical com-

ponents in the new building, the same number of identical components needs to be reclaimed from, in the most likely case, one single building. This can be a significant barrier for mainstream adoption.

Difficulty to match supply and demand

Unlike newly produced components, reclaimed components are not made to fulfil a demand in the market. The production process, circular demolition, is a service in itself which enjoys its own demand. This creates a difficult situation in which the timing of a demolition and a newly constructed building become essential for the prospects of finding demand for components that can be reclaimed. This difficulty endures because there is no universal way for communication between the supply and demand side.

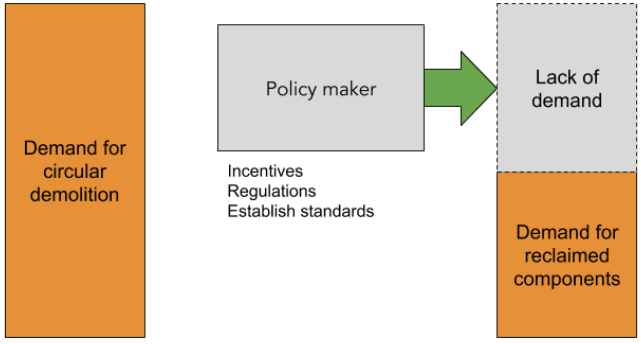

Figure 6.1: Influence of policy maker on demand.

6.2.3 Environmental Barriers

Environmental drivers are the primary reason to attempt component reuse. It is important to see if there are also barriers present in this pillar. While not found as a barrier in any of the cases the extra steps and transport in the supply chain should be considered in the environmental impact of reused components.

Health risks

Health risks are an important concern both during deconstruction and after reuse of components. It is common to find asbestos, lead, or other hazardous materials in old buildings. The presence of these materials makes reclamation for reuse impossible. Asbestos is the first thing many people think about with hazardous materials encountered in the demolition of buildings. However, there are numerous other materials that can pose significant treats to the health of the deconstruction workers, or if they remain undiscovered the health of users of the new buildings. Rotor DC has encountered this problem with wooden floors. Formerly these kinds of floors were often installed on top of a subfloor made of bitumen. If the floor contains tar it becomes carcinogenic.

Energy regulations

In the construction of new sustainable buildings energy use usually gets prioritised over component reuse. Since reclaimed components are often mined from older buildings, the energy performance is not state-of-the-art (B. van Dinther, personal communication, April 18, 2018).

6.2.4 Behavioural Barriers

Behavioural barriers often manifest themselves as economical barriers but require a shift in the way of thinking of potential stakeholders to be overcome. The barriers identified in this analysis result in a lack of demand for reclaimed components, which has been discussed in section 6.2.2. While the demand for circular demolition is growing, analysis of the two client cases has shown that the very companies that deconstruct their old buildings are unwilling to reuse the reclaimed components in their new buildings. The demand for reclaimed components is falling behind the supply of reclaimed components. The main reason that has been found in all the analysed cases is that of a (perceived) lower quality of reclaimed components. Perceived, in the previous sentence, is between brackets because not all of the interviewees considered it a matter of perception.

The perceived value of reclaimed components is apparent in the facilitating cases. Lionel DeVlieger stated that they have to sell washbasins of high quality for low prices because they compete with cheap newly produced products that are of inferior quality. In a similar vein Rob Gort from Bouwcarrousel experienced a low demand for high quality building components, partly due to the image of second-hand components. The same conclusion was reached by Pomponi & Moncaster (2016) who not that people do not want to buy components for their fancy new buildings at the scrapyard. The

two client cases of RVB and Erasmus MC confirmed these statements in an interesting way with people stating in informal and formal interviews that low quality of recycled components is a barrier to reuse, while other agreed that it was a problem of perception. Iacovidou & Purnell (2016) expect that the "changes in the perceived value of reclaimed construction components are likely to increase demand for these components in the near future".

Lack of demand for reclaimed components

Demand for some reclaimed components, like antiques and especially valuable components has been identified as a driver for component reuse. However, for the lion's share of materials demand remains low. A serious lack of demand for many components prevents reclamation from being economically viable. This barrier has also been described as an economic barrier, because that is how it manifests itself, but the root is behavioural and elaborated upon in the next two barriers.

Perceived lower quality of reclaimed components
Reclaimed components have a lower perceived quality than new components (Densley Tingley et al., 2017). RotorDC manages to find new destinations for many components because of their focus on high quality. Even so, they have trouble competing with new components of lower quality and a higher price. An example of this are sinks of high quality manufacturers in pristine condition. Rotor DC has enough of these sinks in stock to outfit some moderately sized buildings. This is exactly what they are planning, but thus far potential buyers seem to prefer cheaper made new products. In a similar vein Erasmus MC will deconstruct two buildings while aiming for a reuse rate that is ambitiously high. Even though the reclaimed components are of high quality and some of them have historic value to the hospital, the choice has been made not to reuse any of the reclaimed components onsite because of quality requirements for the new hospital.

On the other hand, while Bouwcarrousel has struggled with the same issues in the Netherlands, they have found the opposite to be true in countries of eastern Europe. According to Rob Gort the perceived quality of reclaimed German made materials is higher than that of new Chinese made materials. Hence, the sale of many containers full to other countries where the perception is different.

It is important to note that this barrier is purely about perceived quality of components and materials. The actual quality does not necessarily match and can be lower or higher than the perceived quality would suggest.

Perceived architectural limitations

According to Bert Albers, manager of sustainability and architect in the RVB, designing with reclaimed components limits design possibilities. Therefore, RVB considers the lack of architectural freedom a deal breaker, because of their high architectural ambitions. This statement underpins the validity of Rotor DC's strategy of reclaiming high-quality materials with a story that enjoy a higher demand. The inclusion of these unique elements in a design makes the design stand out. However, just like the previous behavioural barrier this is a matter of perception. While it is true that

This barrier is but a single cause for the lack of demand for reclaimed components and has only been encountered in one of the four cases. As such it is not necessarily the most important cause but is deemed relevant because of its relation to the need for information in the design phase of a project. Since reclaimed components are unique designers require technical information about the reclaimed components early in the process. This can pose difficulties in ambitious projects with a traditional schedule.

6.2.5 Societal Barriers

Where the behavioural barriers require a shift in perception to be overcome, societal barriers are inherent in the way society or in this case companies work. Societal barriers can be found within companies, between companies, or in the broader society.

Requires knowledge of materials in the design phase

The use of reclaimed components requires the design team to be aware of the availability and technical characteristics of the components in the design phase. Because of the way supply chains are normally set up in the construction industry information only flows one way.

Traditional procurement methods

Standard procurement practices do not allow for the use of reclaimed components. Since the pro-

curement of materials is often delegated to subcontractors there is little incentive and high risk to think out of the box (R. Gort, personal communication, Mei 19, 2017). For this reason, use of reclaimed components can only happen if it is specifically mentioned in the tender brief.

Lack of transparency

Lack of communication between potential customers leads to untapped potential. This barrier stems from the manner in which the supply chain in the construction industry has worked for many years.

Absence of working supply chain

There is currently no functioning supply chain or market for reclaimed components in the construction industry of the Benelux.

Inertia in the existing chain leads to slow adaptations to changes. There is very little incentive to look further than the established supply chains.

6.2.6 Technological Barriers

While there are technical challenges and barriers for component reuse, the cases suggest that they are not the primary bottleneck for achieving more reuse. Components that do not come with technological difficulties such as doorknobs, which can easily be disassembled and reused, are still not reused at great scale. Nonetheless it is important to include technological barriers in the overview.

Quality control

Newly produced components can easily be tested on quality in the production process and come with certificates as proof. For reclaimed components quality control is a technical challenge because wear during the use phase is undocumented and not always visible. Especially for structural elements the reuse would

Need for human expertise

Thus far there has been no technological breakthrough for the identification and sorting of reusable components. While this is not a technological barrier, developments that would minimise the need for human expertise can become important opportunities. The development of software such as material passports, or tools that assist the inventory of components are being worked on by actors involved in the cases such as Madaster and Rotor DC.

Part III - Synthesis of opportunities

This chapter is about the synthesis and discussion of (business) opportunities for component reuse. Some opportunities discussed here have been identified in the cases just like the drivers and barriers, others were discovered through the analysis in part II.

7.1 Observations on Drivers & Barriers

The multiple case study revealed the existence of drivers and barriers in all six of the influence dimensions. However, when a distinction is made between a supply and demand side, drivers and barriers are concentrated in specific influence dimensions. Barriers are concentrated in the behavioural dimension on the demand side, while drivers are concentrated in the governmental dimension on the supply side. Both the technological and environmental dimensions were expected to be super important for circular economy problems, but neither pillar houses any of the principal drivers or barriers.

	Governmental		**Economic**	
	Supply	*Demand*	*Supply*	*Demand*
D	Zero waste goal		Profit	Profit
B		Tender Rules Tax system Liability	Limited Supply Price of transport Price of storage	Limited Demand
	Environmental		**Behavioural**	
	Supply	*Demand*	*Supply*	*Demand*
D			Demand for circular demolition	
B	Health risks	Energy efficiency		
	Societal		**Technological**	
	Supply	*Demand*	*Supply*	*Demand*
D	Company policy		Online database	
B				

Table 7.1: Influencing factors sorted by category.

Circular economy is rooted in the belief that economic drivers will arise as resources become scarcer (MacArthur, 2013). In the case of component reuse in the construction industry however, the economic dimension is largely filled with barriers. This lack of economic drivers is a considerable obstacle in the establishment of a circular construction industry. The rise of economic drivers for component in the near future seems unlikely but on the other hand case results and other researchers expect behavioural barriers to be overcome and demand for reclaimed components to rise (Iacovidou & Purnell, 2016). This rise in behavioural drivers has the potential to overcome economical barriers.

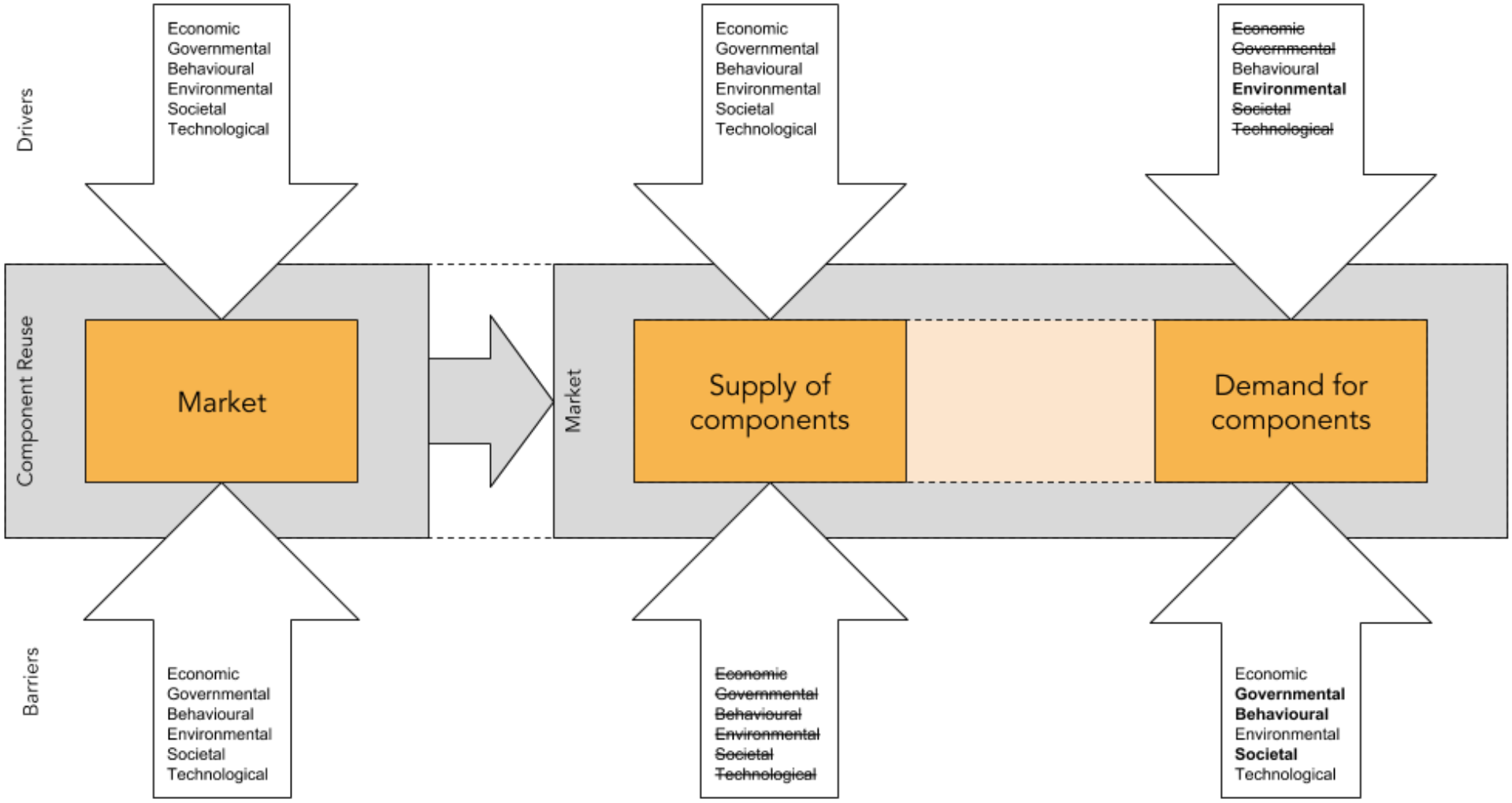

Figure 7.1: The placement of drivers and barriers in the analytical framework.

The finding that most drivers are not environmental, and most barriers are not technological might seem counterintuitive, but this shift in perception allows for the mitigation of barriers by finding opportunities in different domains. The extra difficulties present in a circular supply chain, however, are not the only big barrier that needs to be overcome. Behavioural barriers prove equally hard, if not harder, to overcome. While a lack of transparency in the supply chain is often mentioned by actors that are starting out in the field of component reuse, the more experienced actors experienced negative connotations in would be customers. Noting that people do not want to buy components for their fancy new buildings at the scrapyard (Pomponi & Moncaster, 2016).

The start of a shift in public consciousness has taken place. The desire to minimise waste has led to individuals within different organisations to be asking the same question: What happens to the materials of their buildings once they are demolished? Because of this there is a market for circular demolition but not for the resulting components.

7.2 Opportunities

To answer the question, "Which opportunities for component reuse can be found in current cases?", the meaning of the word opportunities in the context of this research needs to be established. Opportunities are possibilities for creating profit-making ventures? Opportunities can be possibilities to overcome barriers, but they can also be untapped possibilities where there are no barriers.

In spite of a multitude of drivers and opportunities it has to be concluded that the analysed cases do not represent a fully functional market. The analysed cases are not the only initiatives aiming to make component reuse mainstream, but they are representative for the market as a whole. Therefore, it can be stated that there is no functioning market for reclaimed building components in the Benelux. The absence of a market can be explained by the drivers not being strong enough to overcome the barriers. The opportunities that have been identified can be utilised to, but the question remains if they are big enough opportunities to establish a market.

To be able to determine opportunities for the stimulation of a market for reclaimed building components an analysis will be carried out from the point of view of the most likely stakeholders in this market, entrepreneurs and policy makers.

Willingness to engage

Both government and private organisations is a high willingness to engage in projects that aim to close material loops. Rotor DC is supported by local government in their accommodations and warehouse, RVB is part of the Dutch government and involved in various projects with circular goals. Based on the analysed cases however, this willingness to engage is largely limited to the supply side, rather than the demand side. New companies are founded with the goal of reclaiming building components and circular demolition practices are becoming more mainstream. Circular construction however, is thus far mainly limited to a limited number of projects. Even buildings designed to be circular often use components sourced from virgin materials. Regulations and standardisation of quality testing

The lack of regulations for reused components cause uncertainty on the side of potential customers. The brainstorm sessions with professionals from both construction and demolition companies revealed that nobody has a clear notion of the legal possibilities with reclaimed components.

Rotor DC on the other hand sees the rise of regulations and formalised quality testing as a tread to the market for reclaimed components. Lionel DeVlieger fears that mandatory tests for a seal of quality, similar to those already in place for new components, would drive up prices so high that the margins would be too low to stay profitable. This is a valid concern and before any regulations or quality testing is implemented more research will be necessary. At the same time, however, the case of Rotor DC shows how big gains can be made in the reuse of 'risky components'. Since they do not reuse any structural elements.

Unused potential

Demolition companies judge the likelihood for resale on their own experience. If the conclusions of different demolition companies do not overlap, this means that there is a bigger opportunity for reuse. In the tender of RVB this turned out to be the case, Bert Albers has identified untapped demand by comparing the offers for their tender and discovering a discrepancy between the components deemed suitable for reuse by different companies.

Portfolio mining

If the portfolio of a single company is sufficiently large reclamation and reuse could be realised within the stock of this company. This means that

some barriers, like taxes and uncertainty of demand, can be circumvented but leads to the internalisation of some other barriers. Therefore, a company attempting to seize this opportunity must be aware of the necessary investment? Portfolio mining was classified as opportunity because a company that is sufficiently large and willing, could integrate supply and demand without overcoming the most difficult barrier of lack of information. Even though portfolio mining provides opportunities to overcome the barriers mentioned before, the effects of other barriers is heightened. The smaller pool of new buildings means that demand for re- claimed components is unlikely to occur naturally. Because of this, the deconstruction of old buildings needs to coincide with the construction of new buildings. In the case of Erasmus MC, portfolio mining has been considered but turned out not to be an option due to the constant need for floor space. If the floor space of the building that is to be demolished is in use until after completion of the new building.

Different procurement practices

A big opportunity has been identified in the adoption of alternative procurement. The questions asked in most tenders put the acquisition of materials on sub-contractors, who have no incentive to stick out their necks to use reclaimed components in a project. Tenders in which is specifically asked for reused components, as is now the case for circular demolition, could fix this barrier but there could also be an opportunity for tenders that allow the subcontractors more freedom in this matter.

Technological advancements

Technological advances would be helpful in many parts of the reuse process. Starting from the identification and inventory of components, which is still a largely manual process. To better communication protocols for exchanging information on reclaimed components. The question remains to which extends processes can be automated. Initiatives to develop software to facilitate the two uses mentioned above are being developed, but still require experts to use them.

Tax system

Even though the current tax system cannot be classified as either a driver or a barrier there is without a doubt room to turn it into a driver. Reclaimed components are charged the same value added tax as newly produced components, even though this tax has already been paid at the original sale of the component.

7.3 Synthesis of Opportunities

7.3.1 Synthesis for Policy Makers

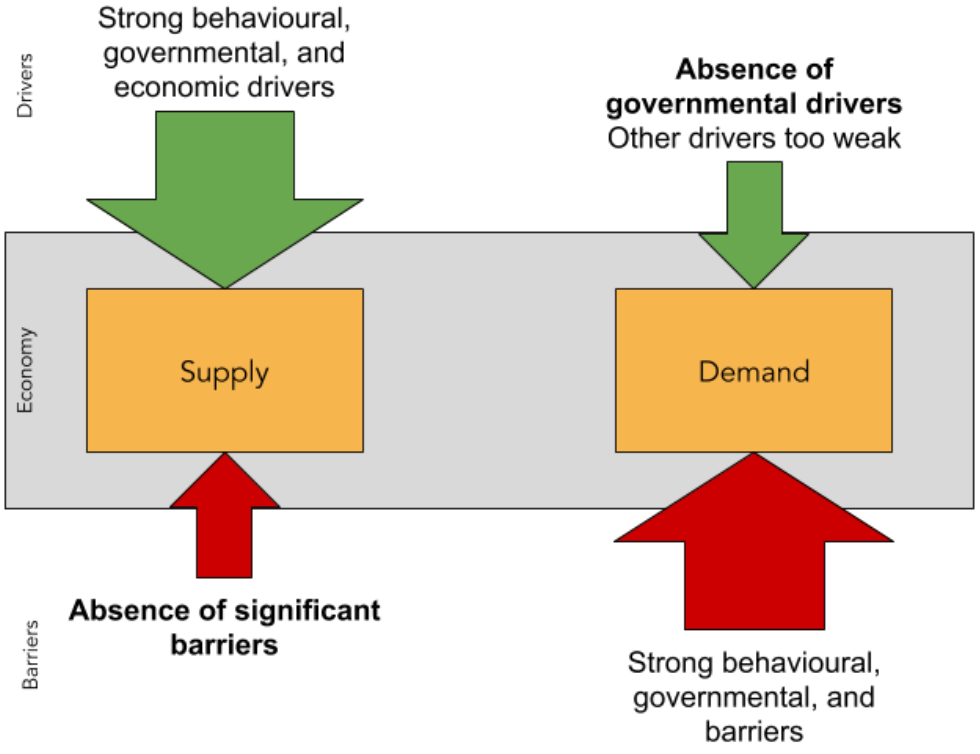

Figure 7.2: The impact between drivers and barriers.

The majority of drivers that have been identified in this study are environmental and behavioural drivers. Strong economic drivers that would beneficial for circular economy are largely absent for materials in use in the construction industry. Component reuse should nonetheless be preferred over recycling in scenarios where it is feasible (Hendriks & Janssen, 2003). Pomponi & Moncaster (2016) argue that that there is interaction between the six dimensions in the framework for research into circular economy in the built environment. The interaction between different dimensions is not necessarily equal. When drivers and barriers enter the equation, dimensions from the 'drivers side' can influence specific dimensions on the barriers side, identifying these interactions can help to identify opportunities.

The analytical framework of this study shows how drivers and barriers from different dimensions influence circular demolition (fig. 4.3). In figure 7.1 the specific interactions found in this study have been visualised showing that not all drivers and barriers are present everywhere in the supply chain. This can be further simplified, as has been done in figure7.2.

This shows that the drivers for circular demolition are bigger than the barriers, hence the rising demand for circular demolition. However, on the demand side for reclaimed components the barriers outweigh the drivers. The creation of governmental drivers on the demand side could be used to overcome this barrier. The legislation on waste minimisation has been showed to work. Since there is currently no legislation encouraging component reuse similar results can be expected.

7.3.2 Synthesis for Entrepreneurs

Niche of facilitating

There is a clear niche in which the reuse of components makes sense and is already financially viable. RotorDC fills this niche, components with high value enjoy a steady demand. From the perspective of a facilitator, both supply of components and demand for reclaimed components are a demand for their services (Fig. 7.3). A problem is that circular demolition is not circular if reclaimed components do not get reintroduced into the loop. Therefore, the question to be answered by the party taking this position is: 'what can I do with the oversupply of materials'. A facilitating company with a good strategy for this can find opportunities in the market.

Craftsmanship or technology

At this point in time component reuse requires craftsmanship at vital points in the value chain. The identification, valuation, and reclamation are currently done by experts in the sample cases. The evaluators of Rotor DC are people with university degrees, rather than conventional demolition workers. Contrary to more traditional ways of procurement the components often have to be an integral part of the design. Not only does this limit architectural freedom, it also makes information exchange between actors that usually don't exchange information necessary. If a system that eases the appraisal of components as well as the sharing of information were to be developed many new opportunities would open up.

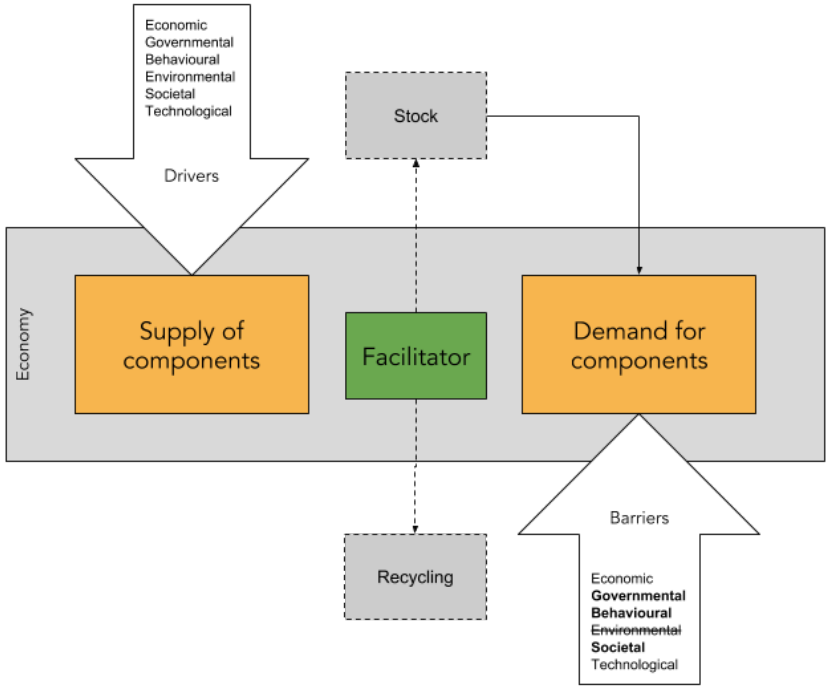

Figure 7.3: Demand from the perspective of an entrepreneur

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Conclusion

The challenge of making the construction industry circular is being tackled by many actors with different approaches. The most popular approach is to look at it from the perspective of new buildings that will one day be demolished. Less popular but equally important is to approach the challenge from the perspective of the current building stock. Circular demolition is gaining in popularity, but demand for reclaimed components is not rising proportionally.

The opacity of supply chains in the construction industry lead to barriers for attempts to reuse components. Among the studied cases there is a consensus that the reuse of construction components is hindered by a lack of information about available components, or exchange thereof. This barrier is the most obvious and solutions are actively being worked on. Solutions thus far have been technological in nature

While there are plenty of opportunities to create a profit-making venture, it can be questioned to what extend these endeavours actually stimulate component reuse. Since the demand for circular demolition is larger than the demand for reclaimed components, many reclaimed components could end up in untapped stocks or eventually be send off for recycling.

1. What can current cases reveal about the drivers of reclaiming building components from existing buildings and their reuse in new buildings?

There is an economic argument to be made for circular demolition. However, this is usually not the driver for the decision to carry out a demolition project in a circular manner. Rather, it helps to remove barriers, after all, if it is economically feasible and there are other drivers present, why not try it? The principal drivers to start a circular demolition project have been found to be behavioural, governmental, and environmental. The human factor is important for projects like this, both in companies with buildings to demolish as in demolition companies, environmental awareness has led to individuals trying to find solutions to demolition in which the materials are not going to waste. The economic viability and shifting societal awareness causes the initiatives of these pioneers to be accepted by organisations and become part of demolition projects. The second principal driver is governmental and stems from the zero waste goals set up by the government. The zero waste goals for the year 2050 drafted by the national government have already caused companies to look for alternative demolition methods. While these goals do not contain regulation to promote reuse over recycling, the distinction is made within the document leading companies following the governmental goals to explore possibilities for circular demolition. Both of these drivers originate from environmental concerns, which also led to the lifting of societal, allowing these projects the possibility to flourish.

There are not many drivers for the incorporation of reclaimed components into new buildings. Since the materials used to make construction components are generally not scarce enough to drive up the prices.

2. What can current cases reveal about the barriers of reclaiming building components from existing buildings and their reuse in new buildings?

The main barriers for reclaiming building components are the extra labour and time required to incorporate the disassembly of components into a demolition progress, as well as the lack of demand for the resulting reclaimed components. However, as mentioned above these barriers are outweighed by the drivers.

While it could reasonably be expected that circular demolition and component reuse are part of the same market, and thus supply and demand should balance each other out, this is not the case. Reuse of reclaimed components in new buildings is a different matter from circular demolition with different drivers and barriers involved. Furthermore, the barriers are more powerful than the drivers. Much like on the side of circular demolition behavioural drivers and barriers have proven to be important for the adoption of component reuse. The perceived quality of reclaimed components prevents the use of them in new buildings. The principal barriers to component reuse are of a societal nature. There are numerous organisational difficulties to the integration of reclaimed components into new buildings, which have been proven to be critical barriers. The limited supply of identical components is a barrier for adoption in big projects and the lack of standardisation requires designers and contractors to know about the components ear-

ly on in the project. The use of reclaimed building components in a project requires significantly more communication between actors and often requires two-way communication between actors that only communicate one-way in a traditional project. These are not barriers that cannot be overcome, but the lack of economic and governmental drivers leads to a low interest in component reuse.

3. Which opportunities for component reuse can be found in current cases?

The demand for reclaimed components falls behind the level of circular demolition or deconstruction. This demand for circular demolition, but lack of demand for reclaimed components can lead to either a stock up of supply, as has happened in the case of Bouwcarrousel, or the decision to recycle rather than reuse components that could be reused as is the strategy of Rotor DC and Van Liempd. While economic drivers are not substantial enough to overcome the extra complications in the supply chain and the design process, governmental drivers can help out to achieve a similar societal shift as is already in progress for the reclamation of building components. For governments that want to stimulate component reuse the lack of governmental drivers shows that the creation of those could help facilitate the economic and societal barriers to be overcome.

The drivers for demand for circular demolition are rooted in societal and governmental shifts rather than stemming purely from economic drivers. For companies aiming to take a facilitating position their barriers are mainly in the demand for reused components. Demand for circular demolition is growing. This is an opportunity that can be seized provided that a strategy for the storage or processing of reclaimed materials is in place.

The answers to the three secondary research questions above can be summarised to answer the research question: “What are the current drivers, barriers, and opportunities for circular demolition and the integration of component reuse into new buildings in the Benelux?”

The findings show that the drivers are mainly on the side of the demolition of old buildings. Building owners recognise the value of materials and components and are open to the possibility of reclaiming components for reuse. The drivers stem from environmental awareness of the decision makers or individual employees, as well as policy that promotes the minimisation of waste. Barriers have mainly been found on the demand side for reused components. The same environmental awareness that is driving the growth of circular demolition has thus far not led to a significant increase in demand. Furthermore, in contrast to the governmental incentives for waste minimisation that encourage circular demolition there is no specific policy for encouraging component reuse. Barriers to the reuse of reclaimed components in new buildings are mainly of a behavioural and societal nature since there is a negative association with used components and the integration of them into new buildings requires substantial organisational changes to the design and procurement processes.

Opportunities are plentiful, as proven by the success of some of the analysed cases, but from the perspective of an entrepreneur there is a big risk involved in exploiting them. Since the demand for reused materials is lower than the demand for circular demolition the risk of overstocking reclaimed components is apparent, in turn making the business vulnerable to business cycles. From the perspective of a policy maker there are several opportunities to be exploited. The lack of any regulations specifically promoting reuse or closed-loop recycling over open-loop recycling leaves this space right open for policy makers to step in.

Discussion

Emergent opportunities have been identified from the drivers as well as the barriers. However, the validity of opportunities is extremely difficult to test without actually attempting to utilise the identified opportunity. Therefore, the opportunities identified in this paper remain hypothetical unless already exploited within one of the cases. The drivers and barriers however have been identified by the analysis of four representative cases.

The heart of the matter is that opportunities are challenging to identify, even after having identified the drivers and barriers. A lack of quantitative data means that the validation of opportunities taken by in the cases is largely based on assumptions. While it is possible to identify possible opportunities that have not yet been taken, they cannot be validated without actually attempting to utilise them.

In the pursuit for the reuse of reclaimed building components it is easy to forget that other options are available as well. In many cases it might be preferable to do high quality recycling rather than reuse. Barriers to component reuse, especially economic barriers, might not need to be overcome if there are high value closed-loop recycling alternatives. An avenue for further research could be about this question: when to attempt component reuse over recycling?

Further research

The explorative nature of this study leaves open many paths for further research, both within the scope of this research and expanding upon it. The drivers and barriers that have been identified are representative for the supply side but not exhaustive for the demand side. Therefore, a possibility for further research would be a similarly set up study with a focus on the demand for reclaimed components.

More interesting in my opinion though, would be to follow through on the opportunities that have been identified in this study and test their validity.

The lack of standardisation in the evaluation process of materials of buildings that are to be demolished opens possibilities for the development of standardised methods. These methods would be helpful for the advancement of circular demolition and serve as a basis for policy makers.

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Appendix A – Overview of Drivers and Barriers per Case

			Van Liempd	Bouwcarrousel	RotorDC	RVB	ErasmusMC	Notes
Drivers	Governmental	*Zero waste goals*			I	I		
		Subsidies for cirular initiatives			I			Belgium
	Economic	*Short term profit (cost savings)*	*I*	S		I	I	
		Long term profit (experience/sale)		I		I		
	Environmental	*Resource efficiency*	*I*	I	I	SE	SE	
		Taking care of the environment	*S*	S	S	P	SE	While 'environment' is a very broad definition, this reason is mentioned universally as a driver.
	Behavioural	*Company policy*			I	I	SE	
		The human factor		I	W		I	
		Demand for circular demolition	*I*	I	I	W	O	RVB and ErasmusMC show demand for circular demolition
	Societal	*Corporate image*				I	I	100% of the corporations
		Role in society				S	I	
	Technological	*Online sales platform*	*W*	W	W	W		Facilitator rather than driver
			Van Liempd	**Bouwcarrousel**	**RotorDC**	**RVB**	**ErasmusMC**	
Barriers	Governmental	*Tender Rules*	*I*		I	I		
		Unclear regulations		P		I	I	
	Economic	*Extra costs of demolition*		S				
		Time constraints for deconstruction					I	
		No demand for reclaimed components	*I*	I	P		I	RVB did not experience this because they outsourced the sale of components
		Price of transport and storage		P	P		SE	
		Matching supply and demand	*I*	I	I	I	SE	ErasmusMC main topic of the seminar
	Environmental	*Health risks*		S	I		I	
	Behavioural	*No demand for reclaimed components*	*I*	O	I	O	I	In there twice, this one is more about perception
		Perceived lower quality of reclaimed components	*I*	I	O	I	I	RotorDC acknowledges this by only focussing on the select components that do have demand
		Architectural freedom				I		Only explicitly mentioned by RVB
	Societal	*Traditional procurement methods*		I	I	I		
		Lack of experiece					I	
		Lack of transparancy				SE	I	Both RVB and ErasmusMC embarked on partnerships to improve this
	Technological	*Quality control*		I	I	I	I	
		Requires knowledge of materials in the design phase			I		I	
		Lack of supply chain integration		I			I	
		Extra complexity in supply chain			I	I	P	
			Van Liempd	**Bouwcarrousel**	**RotorDC**	**RVB**	**ErasmusMC**	
Opportunities	Governmental	*Regulations for reuse*	*I*		I			
		Willingness to engage in projects			I	I		
	Economic	*Portfolio mining*			I	P	SE	Makes matching supply and demand even harder due to limited demand side
	Environmental							
	Behavioural							
	Societal	*Unused potential (lack of transparancy)*	*I*	I	I	I		There is more demand than is utilised
		Different procurement practices						
	Technological	*Standardisation of quality testing*		I	P			

SE = Mentioned in seminar
I = Mentioned in interview without prompting
P = Mentioned in interview after prompting
S = Mentioned in secondary information
O = Observation
W = Mentioned on website

Appendix B – Interview Questions

Interview questions for clients

1. What are your experiences with circular demolition?

2. Why did you decide to do circular demolition?

3. Did you encounter barriers in the circular demolition and reuse of materials or components?

4. Did you identify any new opportunities in the process?
a. Have any of them been exploited already?
b. Do you expect to exploit any of them in the future?

5. What does the circular demolition process look like?
a. Do you make use of material passports?

6. What percentage of materials and components of a building is reclaimed?
a. What percentage of this finds a new destination?

Additional questions

1. Have you considered the reuse of reclaimed components within your own building portfolio?

Interview questions for circular demolition companies

1. What are your experiences with circular demolition?

2. What is the reason for your company to do circular demolition?

3. How big is the interest coming from construction and demolition industries
   a. For circular demolition?
   b. For reclaimed components

4. Do you run into barriers in circular demolition projects or in the sale of the reclaimed components?
   a. Have you found any solutions to overcome these barriers?

5. Have you identified any opportunities for the further development of component reuse?
   a. Do you see a future in which component reuse has become the standard?
      i. What needs to happen to make this a reality?

6. What does a circular demolition project look like for your company?
   a. How do you approach the inventory of components?
   b. Do you make use of material passports?

7. Do you see possibilities for the reclamation of structural elements?

8. Which part of the materials and components from a demolition project finds a new destination?
   a. How does this compare to regular demolition projects?
   b. Which share is sold directly from the demolition site/which share is put into storage?
   c. How long does it take for components in the depot to be sold?