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Management of resources and waste in the construction and real estate industry

The case of the Circular Office

Master's thesis in Design and Construction Project Management

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Preface

This thesis was conducted as a final effort in our master program *Design and Construction Project Management* at the Department of Architecture and Civil Engineer, Chalmers University of Technology. This thesis was carried out during the spring of 2020 and corresponds to 30 ECTS.

Firstly, we would like to express our gratitude to our academic examiner Martine Buser for steering us in the right direction and for her support and motivation throughout this process. We thank Per Östling from the 360 space program for his inspiration and positive energy as well as bridging us with Castellum.

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Abstract

Construction and demolition waste (CDW), and the associated resource use, is a major contributor to the overall waste generation in Europe and in the world. This leads to serious environmental issues. Circular economy (CE) is seen as a potential solution to this problem, as it can lead to more efficient resource use and minimizing of waste, along with social and economic benefits. To apply principles of circular economy to company's business models, business model innovation is needed. The main aim of this study was to identify the status of CDW and the challenges, barriers, and opportunities at the case study company (Castellum) and offer recommendations of CE principles to be implemented in the company's business practices, thus achieving circular business model innovation and reduce the environmental impact of the case study company. This paper comprises of a theoretical framework surrounding the topics at hand, empirical data collected through a qualitative research method, and an analysis of the data with recommendations for the case study company.

Keywords: construction and demolition waste, resource use, construction industry, real estate industry, circular economy, business model, business model innovation, circular business model innovation

Contents

"Waste is material without an identity"

- T. M. Rau, Architect

"A more modern and circular economy will make us less dependent and boost our resilience. This is the lesson we need to learn from this crisis"
[Amid the COVID-19 crisis]

- Ursula von der Leyen, President of the European Commission

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List of Abbreviations

BIM – Building Information Model

CBM – Circular Business Model

CBMI – Circular Business Model Innovation

CDW – Construction and Demolition Waste

CDWM – Construction and Demolition Waste Management

CE – Circular Economy

CP – Circular Procurement

CSF – Critical Success Factor

DfD – Design for Disassembly

EC – European Commission

EU – European Union

LCA – Life-cycle assessment

Paas – Product as a service

SWMP – Site Waste Management Plan

VR – Virtual Reality

1. Introduction

The first chapter is intended to give the reader insight into the problem that led to the choosing of this thesis topic. It includes a background of the problem context and major themes imbedded in the work. The first topic selected was construction and demolition waste, which upon the initial literature review was expanded with resource use, as it is undividable from the concept of waste. To tackle this issue, the concept of circular economy was chosen as the second main topic based on the literature review of the first topic. As business models describe how a company does business, they were chosen as the third main topic. To get a practical overview of the topics chosen, a case study was performed with Castellum, a Swedish real estate company. Further on the aim and purpose of the thesis are explained and the main research questions are posed, along with the scope and limitations of the paper.

1.1 Background

Construction and Demolition Waste

Womack and Jones (1996) define waste in the following way:

"Waste is any activity which absorbs resources but creates no value."

Construction and demolition waste (CDW) is a generic term that defines the waste generated by the economic activities involving the construction, maintenance, demolition and deconstruction of buildings and civil works (Gálvez-Martos et al., 2018). CDW is characterised by its high volume and weight but with probably the lowest environmental burden and the highest inert fraction per Mg of all waste streams. Although the specific environmental impact (per Mg) is low if compared with other waste streams, the associated environmental impacts of such a high amount of CDW is an important concern, mostly derived from its logistics and land occupation (Gálvez-Martos et al., 2018). This makes the management of CDW a high priority for environmental policies around the world and in the European Union.

CDW is one of the heaviest and most voluminous waste streams generated in the EU. It accounts for approximately 25% - 30% of all waste generated in the EU and consists of numerous materials, including concrete, bricks, gypsum, wood, glass, metals, plastic, solvents, asbestos and excavated soil, many of which can be recycled, (Eurostat, 2019) but the recovery of materials from buildings at the end-of-life is often unattractive because the waste is hard to separate and contains toxic materials (Acharya et al., 2020).

On the one hand, governments are faced with the challenge of financing and expertise to manage the increasing amount of CDW. On the other, very few in the private sector are keen to invest in the CDW recycling industry given it demonstrates low profits (Bao et al., 2019). This results in an industry that underperforms on its management of waste and resources and is thus seen as an opportunity for improvement in creating additional value, both for the sector and for the society.

The Linear and Circular Economy

The status of CDW is in line with the linear economic models that have dominated our society for centuries, especially in the industrialized world. Circular economy (CE) serves as the alternative to the conventional "take-make-use-dispose" economic development system, so called linear economy, which has led to severe environmental deterioration either by removing natural capital from the

environment or by reducing the value of natural capital via waste-connected pollution (Murray et al., 2017). Circularity is an essential part of a wider transformation of industry towards climate-neutrality and long-term competitiveness (European Commission, 2020).

The CE has been billed as a way to decouple economic growth from environmental degradation; boost firm profitability; increase competitive advantage; and create new job opportunities at the local level (Kama; Webster; Stahel; Ellen MacArthur Foundation; Heese et al.; Giuntini and Gaudette, cited in Linder et al., 2017). A shift in the industry, from a linear to a circular economy, is expected to reduce the waste generation, and reduce its resource use and overall impact, resulting in a circular built environment.

Innovative models based on a closer relationship with customers, mass customisation, the sharing and collaborative economy, and powered by digital technologies, such as the internet of things, big data, blockchain and artificial intelligence, will not only accelerate circularity but also the dematerialisation of our economy and make Europe less dependent on primary materials (European Commission, 2020). It has been estimated that applying CE principles across the EU economy has the potential to increase EU GDP by an additional 0.5% by 2030 creating around 700 000 new jobs (Cambridge Econometrics et al., 2018).

Business models

A business model explains how a company does business, and it can be perceived as a blueprint of the underlying business logic of a company (Richardson; Magretta; Osterwalder and Pigneur; Teece, cited in Guldmann and Huulgaard, 2020). According to Osterwalder et al. (2010) a business model describes the rationale of how an organization creates, delivers, and captures value.

A minimum of three basic components outline a business model: (1) The value proposition, i.e. the product and service offering; (2) the value creation and delivery system that enables the company to generate products and service offerings and deliver them to customers via the company's internal resources and capabilities as well as via its value chain, activity system, business processes, suppliers, partners and customers; and (3) the value capture system, which defines how the firm generates turnover and profit, its revenue sources and the economics of the business (Richardson, 2008).

A traditional linear business model creates economic value for the actors in the value chain (i.e. the focal firm and its partners, suppliers, and customers). By contrast, a sustainable business model entails a broader understanding of value and stakeholders, since it “captures economic value while maintaining or regenerating natural, social and economic capital beyond its organisational boundaries”. The CE needs new business models to translate circular strategies into competitive advantage, company resilience and successful revenue models. A circular business model (CBM) is a type of sustainable business model that integrates environmental and economic value creation by shifting the business logic from generating profits from one-time sales of goods, to generating profits from a continual flow of reused materials and products over time by capitalising on the value embedded in used products (Amit and Zott; Schaltegger et al.; Adams et al.; Bocken et al.; Bakker et al.; Bocken et al.; Linder and Williander, cited in Guldmann and Huulgaard, 2020, Peck et al., 2019).

CBMs are generally considered to be one of the main drivers of CE, and within them, product-as-service (PaaS) or functional sales models have a role to play as incentives for sustainable and long-lived products. Such models are considered to increase as business logic moves from a flow-oriented

(selling as many products as quickly as possible) to a value preservation (be sure to preserve the product as long as possible) model (Stahel, cited in RISE, 2019).

For existing companies wishing to move from a linear business model to a wholly or partly CBM, the company must have its own reserves and owners who are willing to invest in testing a new business model (RISE, 2019).

Case study – Castellum

"Castellum is one of the largest listed real estate companies in Sweden. Property values amount to SEK 95.2 billion and holdings comprise office, warehousing/logistics and public sector properties, covering a total leasable area of 4.3 million square metres. The real estate portfolio is owned and managed under the Castellum brand through a decentralized organization with strong and clear local presence in 17 cities in Sweden and in Copenhagen and Helsinki.

In 2019, Castellum received several awards for sustainability efforts among which: designated Number One in the world by GRESB for the offices-and-logistics sector, as well as the Level Gold award for sustainability reporting from the EPRA (European Public Real Estate Association). In addition, Castellum is the only Nordic real estate and construction company elected to the Dow Jones Sustainability Index (DJSI), joining a select group of companies in the world who perform best on sustainability issues" (Castellum, 2019).

Castellum is dedicated to their sustainability agenda, which is ambitious; "By 2030, Castellum will be fully climate-neutral – including our entire value chain as well as projects, their subcontractors and materials. These represent 98% of our emissions and are the toughest challenge for the industry as a whole, as it is for Castellum" (Castellum, 2019). Also, they have many environmentally certified buildings: "Castellum owns the largest number of environmentally certified buildings among the listed real estate companies in Sweden and Castellum's buildings are 51 % more energy efficient than the Swedish benchmark for premises. Out of the real estate portfolio 164 properties, equivalent to 36 % of the area, are certified according to Green Building, Miljöbyggnad, BREEAM or LEED. Certification is underway for another 2% of the portfolio" (Castellum, 2019).

When it comes to the company's real estate portfolio it "is in growth areas in Sweden, Copenhagen and Helsinki. The commercial portfolio consists of 47 % office, 23 % public sector properties, 16 % warehouse/logistics, 8 % retail and 2 % light industry. The properties are located from inner city sites to well-situated working areas with good means of communication and services. The remaining 4 % consist of projects and undeveloped land. Castellum owns approx. 700,000 m^2 of unutilized building rights and furthermore ongoing projects with remaining investments of approx. SEK 1.2 billion" (Castellum, 2019).

1.2 Purpose and Aim

The purpose of this thesis is to contribute to the general knowledge base on the topic of construction and demolition waste management (CDWM), with an aim focused on improving the case study company's (Castellum's) waste management practices in line with the principles of CE. To get there four research questions are posed:

- RQ1: What is the status of resource use and CDW management at Castellum?
- RQ2: What are the main challenges, barriers, and enablers in improving resource use and CDW management practices of Castellum?
- RQ3: What role do Castellum's various stakeholders play in the management of resources and CDW?
- RQ4: How can the principles of CE improve Castellum's and Castellum's stakeholders' performance on the management of resources and CDW?

RQ1 and RQ2 relate to the core business of Castellum's work, renting of office spaces, specifically the remaking of offices or building new ones for new or existing tenants. What resources are used, materials, how does the process look like, what challenges and barriers exist, and which opportunities are there.

RQ3 aims to investigate the role stakeholders along the supply chain play in the management of waste and resources, these include clients/tenants, designers, contractors, demolition and waste management companies and municipalities/legislative bodies.

RQ4 is aimed to consolidate the findings of the first three RQs to determine what principles of CE are best adequate for Castellum.

The overall aim of this paper is to contribute to the general knowledge base on the topics at hand and to contribute to the case study company's efforts in making their business processes more environmentally friendly through the principles of CE. As this requires business model innovation, various CE principles are studied that could enable the transition towards a CBM.

1.3 Scope

The scope of this thesis was limited by time and thus involved a qualitative study of only one company regarding the topic at hand.

1.4 Limitations

The case study focused only on one real estate company, Castellum, and several stakeholders and suppliers along its value chain, so it is not to be expected that the results can be applied to the whole real estate sector. Also, the financial dimension of the business model innovation was not considered as they fall outside the scope and competences of the authors.

2. Theoretical Framework

The theoretical framework is built upon three main themes: the management of resources and CDW, and the principles of CE, connected through the concept of circular business model innovation (CBMI).

Complementary topics, derived from the literature review and chosen for their relevance in answering the research questions, include the *Customer perspective* and *Elements of Value, Stakeholder Theory* and *Best management practices (i.e. Circular designs, Site Waste Management Plans, Selective demolition, Circular procurement, Adaptive remanufacturing*). These topics were chosen in accordance with the *waste hierarchy* by focusing on the higher levels of waste prevention, reuse, and recycling where a higher impact can be made. Energy recovery and landfill are also briefly mentioned.

2.1 Construction and Demolition Waste

Construction and demolition waste (CDW) is the left-over material from construction, refurbishment as well as road and building demolition (Deloitte, 2017). It is the most significant waste stream in the EU, accounting for over 800 million tonnes per year (including soil). It consists of various material, including concrete, bricks, gypsum, wood, glass, metals, plastic, solvents, hazardous substances (asbestos, PCBs, etc.) and excavated soil, many of which can be recycled. CDW arises from activities such as the construction of buildings and civil infrastructure, total or partial demolition of buildings and civil infrastructure, road construction and maintenance (Deloitte, 2017).

Construction work requires vast quantities of materials. The global extraction of non-metallic minerals (gravel, sand, clay, limestone, and gypsum), reached approximately 35 billion tonnes in 2010. Sand and gravel constituted the main share of global extraction of non-metallic minerals in 2010 (40.8% gravel and 31.1% sand) (Miatto et al., 2017). Infrastructure developments and construction projects are the major end-users of this consumption (Stephan and Athanassiadis, 2018).

Waste has been gaining more and more attention in the EU, and today the prevention and recycling of waste represent the long-term goals of the EU waste policy. These are oriented to increase the EU's resource-efficiency and reduce the negative environmental and health impacts over the life-cycle of resources (Migliore et al., 2020).

According to Avfall Sverige (2018) preventing the creation of waste is the top step in the *waste hierarchy* introduced by the European Waste Framework directive in 2006. It is the priority of both Swedish and European waste legislation.

The *waste hierarchy* priority is:

- waste prevention
- reuse
- material recycling and biological treatment
- other recycling, e.g. energy recovery
- disposal, e.g. to landfill.

The construction sector creates serious environmental problems during the entire lifecycle of buildings, especially during the operation and end-of-life stages. This is mainly due to the generation of CDW and the manufacturing of building materials, (López Ruiz et al., 2020) which makes resource use in the industry another pivotal point of its environmental impact. Associated environmental impacts include land degradation, landfill depletion, carbon and greenhouse gas emissions, water pollution, high energy consumption and resource depletion. Even though there is increasing interest

in implementing recovery practices such as reuse and recycling, in most cases the waste management process is inefficient, resulting in large volumes of waste disposed of in landfills or even illegally dumped without environmental protection measures (López Ruiz et al., 2020). In a study performed by Wang et al. (2010) manpower, market for recycled materials, waste sortability, better management, site space, and equipment were identified as critical success factors (CSF) for on-site sorting of CDW.

In the light of environmental challenges derived from the current linear economy model of "take-make-consume-dispose", the construction industry requires the implementation of new, enhanced building strategies focused on the problem of CDW (Jaillon and Poon, cited in López Ruiz et al., 2020). In this context, the transition to a CE is a potential solution as it would reduce the environmental impacts while contributing to economic growth (López Ruiz et al., 2020). Reducing waste is one of the greatest challenges, and should be one of the highest priorities, for both individual companies and the building sector as a whole (Josephson and Saukkoriipi, 2007).

Materials in buildings should sustain their value where buildings should function as banks of valuable materials and products. This can be done using better design strategies and circular value chains, which are crucial for a sector to reduce both its waste and the amount of virgin resources used by using resources more efficiently. Therefore, new business models are needed which replace the "end-of-life" perception with reducing, reusing, recycling and recovering materials in production, distribution, and consumption processes (Kirchherr et al., 2017).

A recent Danish study found that the building materials of an office building assessed over an 80-year reference study period were responsible for 72% of the total greenhouse gas emissions and 50% of the total primary energy consumption (Eberhardt et al., 2019). After performing a life-cycle assessment (LCA) analysis of an office building Eberhardt et al. (2019) found that the majority of the buildings' embodied environmental impacts originate from many of the structurally important concrete components with long lifespans, e.g. floor slabs and inner walls are responsible for large contributions to the majority of the impact categories. The same LCA also showed that the longer the lifespan and the more reuse cycles the better, as the service life of materials is prolonged. This, in turn, postpones the production of new products consuming virgin raw materials (Eberhardt et al., 2019).

Many studies have indicated that the CDW management (CDWM) strategies such as waste minimisation, on-site recycling, and centralised recycling would have economic benefits, as these methods are generally economically feasible (Wu et al., 2019). For instance, Begum et al. (2006) found that waste minimisation is economically feasible by performing a benefit-cost analysis. However, many studies also indicated that the economic feasibility of CDW recycling would depend on various factors, such as the economics of scale and the methods of recycling Duran et al. (2006). suggested that economic viability is likely to occur when the cost of landfilling exceeds the cost of bringing the waste to the recycling centre and the cost of using primary aggregates exceeds the cost of using recycled aggregates.

The most relevant environmental aspects of CDW generation are influenced by design decisions at the start of the construction value chain; "designing-out" waste is a term in use for CDW and refers to design and planning commercially available techniques to avoid the generation of waste. The most popular designing out waste technique is the use of prefabricated modules, which is more common in modern methods of construction. With this approach, more than 80% of total construction waste can be avoided. For instance, the construction of a new residential building where the structure is prefabricated would save around 80-100 kg of waste per 100m^2 floor area (Gálvez-Martos et al., 2018). Gálvez-Martos et al. (2018) also claim that there are no technical barriers for a virtual 100% recycling

of the main constituents of CDW, concrete and ceramic wastes, but barriers derive from commercialization, the market of virgin materials or their logistics.

2.2 Built Environment and the Supply chain

The built environment - comprised of the man-made elements of our surroundings such as buildings and infrastructure - currently represents a major global consumer of natural resources and a significant contributor to global carbon emissions (Acharya et al., 2020). A recent report by the Ellen Macarthur Foundation titled "Completing the Picture: how the CE tackles climate change", found that a circular scenario for the built environment could reduce global carbon emissions from building materials by 38% in 2050, due to a reduced demand for steel, aluminium, cement and plastic (Acharya et al., 2020).

The research revealed that real estate investors and construction clients are fundamental to driving the transition to a circular built environment because they have the greatest capacity to set the direction and nature of their development strategies, ownership structures and operations models for each project across all stages of life cycles (Acharya et al., 2020).

If real estate investors and construction clients were to integrate CE as an inherent part of their overall business strategy, the building industry would begin to embed circular thinking in investment decisions, revenue models and the supply chain, moving beyond a singular focus on reduced resource consumption towards employing circular models that focus on realising maximum value from real estate assets (Acharya et al., 2020).

A CE approach employs three main principles:

1. Designing out waste and pollution
2. Keeping products and materials in use
3. Regenerating natural systems

Applying these principles to the built environment can create a sector that is resilient to volatile prices of raw materials, that maintains essential natural ecosystem services, and that creates urban areas that are more liveable, productive and convenient (Acharya et al., 2020).

The real estate and construction industry is characterized, among other things, by its complex supply chain, consisting of many different stakeholders. Richardson (2013) has identified that the construction supply chains are usually fragmented, and often involve several parties with different objectives. He argues in his book that none of these parties normally assumes direct responsibility for minimizing or managing waste and that previous research on waste in construction reveal that it can arise at either the upper or lower stream of the supply chain or network. These finding make the management of CDW more complicated, which makes the supply chain a vital part of addressing this issue.

These studies that Richardson (2013) mentions have also shown that the most significant challenging issues within the supply chain to waste minimization come from the nature of the organizations (i.e., contractors, subcontractors, suppliers, etc.), the people that compose the organization and the nature of clients (i.e., one-off customers, government, private, etc.). Clients creating the right environment is considered critical for enabling innovation in the supply chain (Adams et al., 2017b), and is further described in chapter 2.6.

Transition to a circular construction involves changes in value chains, from product design to new markets, from new models of consumer behaviour to new ways of turning waste into a resource. A sustainable waste management system requires vigorous feedback loops and is concentrated on processes to divert wastes from disposal and convert them to secondary raw materials (Seadon, 2010).

To achieve material flows from customers to the manufactures semi-closed loop supply chains need to be established, and these represent a significant challenge for management. Such strategy opens possibilities to recover value from products, and to make this possible, it is necessary to favour selected construction solutions (selective disassembly) (Górecki et al., 2019).

2.3 Circular Economy

Our economies, and our systems of production and consumption, are stressing and damaging Earth's natural systems. We use enormous amounts of raw material and energy to create the billions of products that sustain our lives (Peck et al., 2019). Global extraction of primary materials has been estimated by UN at 70 billion tons in 2010, namely three times more than in year 1970, and this level is projected to reach 180 billion tons in 2050 if our production and consumption models will not change significantly (Migliore et al., 2020). At the same time, we send huge volumes of waste into the very atmosphere, waters, land and ecosystems that are vital to our existence (Peck et al., 2019). The underlying problem lies with our linear economies – these have excessively high material and energy consumption, and eject large proportions of material as waste (Peck et al., 2019).

The combination of these two phenomena—increasing waste production and increasing exploitation of natural resources – makes it necessary to develop new models and paradigms for waste management and for their reuse in place of the increasingly less available natural resources (Migliore et al., 2020). This models and paradigms for resource efficiency and waste management are imbedded in the concept of circular economy (CE).

A CE is one where the resources coming into the economy are not allowed to become waste or lose their value. Instead, this economy would recover those resources and keep them in productive use for as long as possible (Benton et al., 2014).

Kirchherr et al. (2017) and numerous authors have reviewed the academic literature to derive an operational definition and provide the most quantitatively comprehensive reviews of CE definitions currently available. Based on an analysis by Kirchherr et al. (2017) of 114 definitions in the literature on CE, a meta-definition is utilized, "CE is an economic system that replaces the "end-of-life" concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes."

The Ellen MacArthur Foundation (2013) describes CE as 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 aims for the elimination of waste through the superior design of materials, products, systems, and, within this, business models (Ellen MacArthur Foundation, 2013).

Whilst major strides have been made in improving resource efficiency and exploring new forms of energy, less thought has been given to systematically designing out material leakage and disposal. However, any system based on consumption rather than on the restorative use of non-renewable resources entails significant losses of value and negative effects all along the material chain (Ellen

MacArthur Foundation, 2013). A shift to a CE presents the challenge of recirculating direct and indirect material flows in a manner that can promote eco-effectiveness (Webster, cited in Linder et al., 2017).

A CE approach encourages companies to look at their operations and their supply chains, and think about how resources are sourced, how they can be used more efficiently, where they can be more effectively recovered, and where the need for raw materials can be designed out of the business model altogether (Benton et al., 2014).

According to Geng et al., cited in Linder et al. (2017), there is currently no standardized or well-established method for measuring circularity at the micro level that includes businesses and products. This has been recognised as a barrier to implementing circularity in the literature. Linder et al. (2017) analyses the strengths and limitations of some of the existing circularity metrics in the market (see Appendix 1) and proposes a new product-level circularity metric that could address this barrier.

Linder et al. (2017) argues that a robust product-level circularity metric should focus exclusively on measuring circularity as a single attribute of product quality, given that other aspects of quality are captured by other metrics and indicators (e.g., environmental product labels).

It is widely argued that two key elements of this strategy include the servitization of manufactured products through new business models that incentivize material recirculation and products that are designed to have extended life spans (Tukker; Bakker et al.; Kopnina; Stahel; Webster; Lowe, cited in Linder et al., 2017).

CE states that prices of raw materials will increase throughout the future, because of global population growth and the overall increase of wealth. This ties together both economics and sustainability and is what sets CE apart from the other approaches to sustainability: it makes the reuse of raw materials the most obvious economical solution. In other words, CE provides businesses with an incentive to use reused materials, as these will be (and remain) cheaper to use than raw materials that still need to be mined or extracted from the earth (Ploeger et al., 2019). Whole economies could also benefit from substantial net material savings, mitigation of volatility and supply risks, positive multipliers, potential employment benefits, reduced externalities, and long-term resilience of the economy (Ellen MacArthur Foundation, 2013).

Ellen MacArthur Foundation (2013) demonstrates that the principles of the CE—if thoughtfully applied—can provide short-term cost benefits today and some striking longer-term strategic opportunities as well as new profit pools in reverse cycle services (collection sorting, funding, and financing of new business models). According to the Ellen MacArthur Foundation (2013) these benefits consist of a reduction in material bills and warranty costs, improved customer relation and loyalty, and less product complexity and more manageable life cycles.

On the other hand, efforts to transition to a CE have met some critique, de Man and Friege (2016) claim that there are three fundamental problems to achieve this:

1. Production processes lead to the downgrading of materials and to create value from them requires gigantic quantities of energy.
2. The assumption that natural nutrients can be fed back into the ecosphere is flawed at best.
3. The production of beneficial consumer products almost always leads to generation of industrial waste, that often turn out to be hazardous.

de Man and Friege (2016) conclude that circular solutions do not necessarily lead to sustainable solutions, and that they can and do have negative ecological impacts, especially regarding energy use and the risk of certain compounds entering raw material chains.

Rather than applying a one-size-fits-all principle, de Man and Friege (2016) suggest sustainable resource management, that will start from an integrated concept covering waste policy, resource management, energy efficiency, and climate protection. In every single case, an optimal solution must be selected based on economic and ecological priorities. European policy should focus on instruments that can effectively influence the market, with the aim to reduce consumption of scarce materials and to increase the level of material and energy recovery (de Man and Friege, 2016). Only if it includes a mix of strategies and instruments that are optimally geared to provide specific solutions in specific situations, will a policy on materials, product design, and waste be effective (de Man and Friege, 2016).

2.4 Circular Business Models

Circular business models (CBMs) aim to preserve the embedded value of products at the highest possible level of utility by slowing and closing resource loops. The flow of resources through the economy is slowed by an extended product utilisation period or an intensified product usage, and resource loops are closed by recycling post-use materials and re-injecting them into the production system thus extending the material utilisation period (Velte and Steinhilper; Webster; Stahel; Bocken et al., cited in Guldmann and Huulgaard, 2020).

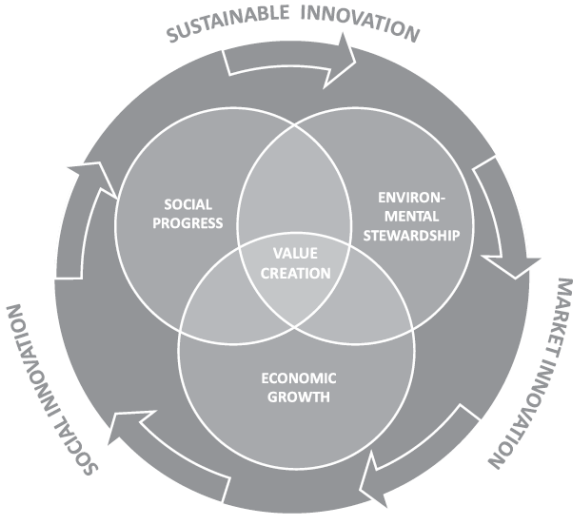

Figure 1. Environmental, social, and economic dimensions of CE (Fehrer and Wieland, 2020).

The existing CBM literature describes four distinct logics for value creation as illustrated in the Appendix 2: (1) Efficient material-technical loops, (2) effective product-service loops, (3) social-collaborative loops, and (4) symbiotic ecosystems (Fehrer and Wieland, 2020). As shown in Figure 1 value creation occurs in the intersection of environmental, social, and economic dimensions.

To help companies adopt circular strategies that can narrow, slow and close resource loops, business model innovation is essential (Peck et al., 2019). The CE needs new business models in order to translate circular strategies into competitive advantage, company resilience and successful revenue models (Peck et al., 2019). Innovating a business model can be done by creating a completely new one or reconfiguring the existing one. According to Peck et al. (2019) this can be done by rethinking the three value dimensions (value proposition, value creation and delivery, and value capture). When looking to innovate a business model in line with the principles of CE, Peck et al. (2019) emphasises

that we aim to move away from linear patterns and to implement actions that narrow, slow and close resource loops. To arrive at such a regenerative economy, companies need to change the way they operate, and the adoption of CBMs is one means to do so (Guldmann and Huulgaard, 2020).

Peck et al. (2019) have identified three key ingredients for a CBM:

- the company should engage in some form of circular value creation.
- the business should make use of value propositions that enable circularity.
- the activities and the business should be embedded in a circular value network.

"Circular value creation", stands at the heart of a CBM. Circular value creation means that the business model should include one or more ways to close, slow or narrow resource loops. Several strategies exist to create circular value, such as recycling, repairing, remanufacturing and reusing (Peck et al., 2019). The value proposition depends on the needs and motivation of customers and can consist of a product-service offering or cost reductions for customers for instance. Also, closing, slowing, or narrowing resource loops is only possible when the stages of a product life cycle are connected in such a way that the product and its resources can be kept inside the economy (Peck et al., 2019). This requires collaboration between the company and other actors in a value network (Peck et al., 2019).

When it comes to the construction industry, Górecki et al. (2019) and other authors think the implementation of the CE must be preceded by the following changes. Firstly, the sector must be theoretically prepared for more efficient business models including knowledge about more sustainable production systems. Moreover, the industry must be equipped with new technologies, facilities, management models and digital platforms to be able to profit from the change. Then, the market must be educated about the financial and ecological advantages of the CE. These findings are however based solely on theory as there are few examples of practical applications and case studies on this matter in the industry.

Furthermore, Górecki et al. (2019) claim that the way a building, road or infrastructure are maintained requires similar evolution as a part of new business models. Secondly, the industry must generate and promote reliable measures of the company's condition being a factor of its propensity to implement the CE. Thirdly, the construction sector should promote policies providing the long-term, reliable financial support for construction projects executed in compliance with the CE principles.

The implementation of CE in BMs, existing or new, based on literature and a case study of school furniture and learning environments in Denmark, requires adopting a stewardship role, formulating and offering a sustainable value proposition (thus embedding environmental, social, and economic aspects), engaging in collaborative circular networks, and partnering and developing suppliers, service suppliers, manufacturers, retailers and customers and, on top of it, understanding how to create value, aiming to create a sharing economy. In a CE perspective, the value propositions of BMs have been changing from providing a physical product to rather delivering functionality via business innovation. (Hofmann; Lieder et al., cited in Kristensen and Remmen, 2019)

Creating CBMs does not come without its barriers. Guldmann and Huulgaard (2020) have identified both external barriers at the market and institutional as well as the value chain levels, and internal barriers at the organisational and employee levels. The barriers at the market and institutional level consist of taxation of labour (as reuse, repair, remanufacturing, are labour intensive) and funding difficulties for CBM, due to the lack of clear market demands for CMBs. Barriers at the value chain consist of investments in existing manufacturing facilities and value chain, concerns about quality and consistency of returned goods, complexity of value chains, and lack of trust and knowledge in the value chains. Barriers at the organisational level include narrow focus on existing sustainability

strategies, difficulty attaining management buy-in, profitability issues as CBM operate on different timelines than linear ones and cannot meet the expected returns on investments, lack of knowledge or competences in-house, and difficulty establishing cross-organisational collaboration. The barriers at the employee level consist of lack of knowledge about CE and CBM, hesitant approach to promoting the CE agenda, prevailing linear business model structures and thinking, and incentive structures that promote them (Guldmann and Huulgaard, 2020).

To summarize, Guldmann and Huulgaard (2020) define circular business model innovation (CBMI) in incumbent companies as the process of reconfiguring an existing linear business model to include CBM components in the form of value recreation, redelivery and recapture and an extended value proposition, or the process of reconfiguring an existing CBM to include more of, or better versions of, these CBM components. Enhanced sustainability or circularity requires changes in the way companies generate value, understand, and do business. Companies are compelled to interact within an ecosystem of actors, moving from a firm-centric to a network-centric operational logic. This transition requires rethinking their incumbent business models (BM), in order to enable a decoupling of value creation and resource consumption (Bocken et al., 2016).

2.5 Barriers and enablers in a CE for the built environment

As every industry is faced with its own set of parameters that define it, so is the construction industry. This causes it to face its own set of barriers and enablers for the implementation of CE. Research on the topic from several authors was consolidated and summarized in this subchapter. The barriers and enablers to implementing CE in the built environment were divided in four categories: cultural, regulatory, financial, and sectoral.

	Barriers	**Enablers**
Cultural	Lack of interest, knowledge/skills, and engagement throughout the value chain (suppliers, customers, and internal) Lack of collaboration between businesses Lack of collaboration between business functions	Leadership – buy-in from top management Environmental drivers Value chain engagement activities to stimulate demand for CE Forming longer term relationships and partnerships Awareness raising campaigns
Regulatory	Lack of a consistent regulatory framework Obstructing laws and regulations - in relation to the handling and categorisation of waste. Lack of incentives for CE	Policy support for skill and innovation Regulatory reform Incentives for CE
Financial	Short-term business perspective High upfront investment costs Low virgin material prices (and low end-of-life value of materials) Poor business case and unconvincing case studies Limited funding	Whole life costing and value measurement Easy wins – like cost savings CBMs Scale of projects – economies of scale Development of higher value secondary markets
Sectoral	An absence of coherent vision for the industry. Complexity of buildings Fragmented supply chains Long product lifecycles Technical challenges regarding material recovery	Better evidence-base – build and communicate better case studies A clearer vision for CE within the built environment needs to be accepted Collaboration and design tools and strategies (BIM, building passports…) R&D and innovation Development of standards

	The lack of standardization Insufficient use or development of CE-focused design and collaboration tools, information, and metrics. The characteristics of the sector – conservative, uncollaborative, adversarial	Development of a reverse logistics infrastructure (take-back schemes)

Table 1. Barriers and drivers for CE in the built environment (adapted from (Hart et al., 2019) and (Adams et al., 2017a)).

As demonstrated, barriers and challenges to implementing CBM in the construction industry are plentiful, so it does not come as a surprise that the industry is as wasteful as described in the previous subchapters and still a long way from becoming circular.

2.6 Customer perspective

Foulkes and Ruddock (2007) have argued that the construction industry spans across the primary, secondary, and tertiary sectors, meaning the extraction of raw materials, producing finished goods, and offering professional services to customers. The real estate industry is especially seen as a service provider. Therefore, consumption and consumers must be of primary consideration for construction and real estate companies trying to increase their involvement in the CE. The lack of market support or demand from consumers is one of the main barriers for small and medium companies to embark on circular projects (Rizos et al., cited in Camacho-Otero et al., 2019).

Adams et al. (2017b) claim that clients have a pivotal role in addressing the challenges to implementing CE within the building sector and driving the shift towards CE from project inception to completion. As such, clients can progress several enabling factors for the uptake of CE, including the implementation of innovative business models, whole life thinking, information sharing, facilitating supply chain collaboration and establishing a clear vision.

The role of the supply chain was considered as a critical success factor with the need for buy-in to enable innovation; however, the client needs to create the right climate for this to occur such as long-term frameworks and partnering along with the acceptance of any potential risk. Warranties and assurance of performance was a continuing theme. A key issue for the client was the requirement for and CE solution not to impact on cost or the construction program – this is where whole life value needs to be considered (Adams et al., 2017b).

To summarize, in order for clients to have a pivotal role, support is needed from the rest of the supply chain such as the provision of new business models, evidence of the benefits of CE applications, technological innovation and provision of performance information and assurance (Adams et al., 2017b).

Generally, there are different elements that influence consumer acceptance of solutions that are considered circular, according to Camacho-Otero et al. (2019). These include factors such as demographic (age, gender, education, location), economic (savings, transactional costs, trust), psychosocial (attitudes, attachment, behaviour, norms, experience…), cultural (social interaction, fashion, identity, status…), and socio-material (impact on everyday life, ease of use, legal and technological issues…). Acceptance and adoption of circular offerings by consumers requires attention to these aspects. However, no single strategy is suitable to address all of them at the same time. Multiple tools are required in order to create offerings that consider all of these aspects (Camacho-Otero et al., 2019).

Furthermore, a study conducted by Elzinga et al. (2020) on consumer acceptance of CBMs showed the profound and reoccurring impact of payment structures as a business model characteristic influencing consumer intention. Altogether, the results suggest that consumers base their decision to participate or to abstain from CBMs on their attitude concerning the foreseen struggles linked to handing in products after use, attitude over being responsible for products themselves, environmental attitude, and most strongly by their habits concerning payment form and responsibility distribution (Elzinga et al., 2020). The study also showed that consumers are less willing to participate in a lease CBM if they are not familiar with paying per month for such a product, but the differed responsibility towards a product when leasing it instead of owning it increased intention to participate in this kind of CBM. Customers are thus seen as vital stakeholders to the construction and real estate industry here, and a crucial part of their value chain.

- *Stakeholder Theory*

According to the existing stakeholder theory literature, business can be understood as a set of relationships among groups which have a stake in the activities that make up the business. Business is about how customers, suppliers, employees, financiers (stockholders, bondholders, banks, communities and managers) interact and create value (Freeman, 2010a). These groups which have a stake in the business activities are referred to as stakeholders.

Freeman (2010b) describes stakeholders as organisations, groups or individuals that are affected by decisions and/or actions of an organisation, and/or who have the potential to influence the actions or aims of an organisation.

In business management, the growing realisation that stakeholders could affect the success of a firm, led naturally to the development of approaches to analyse stakeholders, in order to understand their interests and influence, and how these could support or threaten the performance of the firm (Brugha and Varvasovsky, cited in Reed et al., 2009). Similarly, positive stakeholder relationships are considered crucial for the long-term success of any organisation (Carroll, 1995).

Stakeholder analysis can be defined as a process that (a) defines aspects of a social and natural phenomenon affected by a decision or action; (b) identifies individuals, groups, and organisations who are affected by or can affect those parts of the phenomenon and (c) prioritises these individuals and groups for involvement in the decision-making process (Reed et al., 2009).

Freeman (2010b) argued that stakeholder analysis could improve the strategic management and thus the performance of an organisation. In the development and natural resource management literature, stakeholder analysis has been used instrumentally to overcome obstacles to the adoption of new technologies, adapt technologies to relevant user groups, or to disseminate the same technologies in different ways to different groups (Johnson et al., cited in Reed et al., 2009).

Among the many different methods available for performing stakeholder analysis, analytical categorisations are a set of methods in which classification of stakeholders is carried out by those conducting the analysis based on their observations of the phenomenon in question and "embedded in some theoretical perspective on how a system functions" (Hare and Pahl-Wostl, cited in Reed et al., 2009). Examples of analytical categorisations include those using levels of interest and influence, cooperation and competition, cooperation and threat, and urgency, legitimacy, and influence (Lindenberg and Crosby; Freeman; Savage et al.; Mitchell et al., cited in Reed et al., 2009).

Although interest–influence matrices provide quantitative information about the relative interest and influence of different stakeholders, this information is subjective, contains many hidden assumptions that are not captured in the process of positioning stakeholders on the matrix, and as such have limited replicability. By capturing qualitative information about why different stakeholders have a particular interest (and specifically what this interest is), and why certain stakeholders have more influence than others (and in what contexts), the information gathered is likely to be more useful and replicable (Reed et al., 2009).

- *The elements of value*

As customers (or consumers) are labelled here as one of the crucial stakeholders, how they evaluate a product or service is paramount and needs to be discussed. It has been shown that this evaluation goes often beyond mere pricing. Almquist et al. (2016) have identified 30 "elements of value" that fall into four categories: functional, emotional, life changing, and social impact. Some address consumers personal needs, others external elements.

The idea behind Almquist et al. (2016) model is that it is hard to pin down what customers value and serves as a management tool to determine the best way to add value to their offering. The survey they conducted showed that companies that performed well on multiple elements of value would have more loyal customers than the rest and their researched showed that companies doing well on multiple elements would grow revenue at a faster rate than others (Almquist et al., 2016). Although the study showed that some elements matter more than others, like *perceived quality,* it also demonstrated that there are many ways to succeed by delivering various kinds of value (Almquist et al., 2016).

In order to create and deliver value for customers companies need to take into account these various elements of value, while keeping in mind which of them prove their usefulness in solving business challenges, particularly growing revenue (Almquist et al., 2016). Doing so, according to Almquist et al. (2016), could stimulate new product development that connects in a new way with consumers, new pricing schemes that match the value added, and customer segmentation to pinpoint what each of these groups values and then develop products and services that deliver those elements.

2.7 Best Management practices

The last subchapter of the theoretical framework presents first an overview of some of the best recognised CDW management practices and then a more detailed description of some CE principles relevant for this paper. The aspect of resource use is seen here as an integral part of the overall topic, so is thus also explored. Gálvez-Martos et al. (2018) categorized best CDW management practices in four stages according to the basis of CE: pre-construction, construction, demolition, and waste to products.

A truly circular built environment embeds the principles of a CE across all its functions, establishing a system that is regenerative, accessible, and abundant by design. This means buildings are designed from the outset in a modular and flexible way, sourcing healthy materials that improve occupant wellbeing and minimize use of new materials. They are built using efficient construction techniques and are well utilized thanks to shared and flexible spaces. Components of buildings are maintained and renewed when needed, while building energy use is conserved due to smart technology and product-as-a-service business models. The buildings themselves are designed to be able to adapt to different uses over time, making them resilient to changing market conditions and avoiding premature

redevelopment. When they finally reach the end of their life, the materials and construction techniques deployed allow the buildings to be taken apart in a way that protects the true value of the materials so that they can be used again (Douglas et al., 2019).

- *Pre-construction*

In the pre-construction stage, waste minimization and efficient use of material can be achieved by alternatives focused on optimizing the planning, control, and management of CDW from future construction activities (López Ruiz et al., 2020). Among the practices/strategies available, the following where chosen based on the case study results.

Design for waste prevention provides one of the best opportunities to reduce waste generation and strengthen reuse and recycling practices from the early stage of construction planning and throughout the entire value chain (López Ruiz et al., 2020).

Design for flexibility is used to balance the needs of the present with how those needs will change in the future and to enable change through frequent reconfiguring including reconfiguration of non-structural parts, thus offering flexibility of space (UK Green Building Council, 2019).

Design for disassembly or deconstruction (DfD) focuses on the end-of-life of a project where the largest amount of CDW is generated and constitutes a fundamental strategy for achieving more sustainable buildings by promoting a closed-loop system for building components. It has a significant influence on the amount of potential reusable and recyclable materials and facilitates the operation of recovery practices (Jaillon and Poon, 2014). A materials inventory should be created for the entire building that includes a detailed breakdown of all the building elements that sets out the constituents of each product and material, the structural loadings, and the ability for each material to be reused/recycled, etc. This can be done by applying Building Information Modelling (BIM) (UK Green Building Council, 2019). Designing products or components with an aim for them to be dismantled and reused is a core competency in the CE approach (Ellen MacArthur Foundation, 2013).

However, there are several reasons why DfD strategies are scarce in the current design practice, such as architects have little knowledge about DfD; owners have no liability for the building/facility/ infrastructure end-of-life; most green building rating systems do not value DfD; and, planning for deconstruction may stretch the project's initial schedule and budget. In addition, DfD guides and manuals list a set of design principles to be followed, and although some of them are feasible in today's practices (modularization and prefabrication), others involve major changes in the way design and construction stakeholders operate (e.g., providing standard and permanent identification of materials chemistry) (Cruz Rios and Grau, 2019).

All these circular design strategies are perceived to increase the capital expenditure during the design phase of the project, and to minimize this the UK Green Building Council (2019) suggests engaging designers early in the process. An additional step that can be taken is the creation of a *CDW management plan. CDW management plans* comprise a strategy for project planning and establish waste management measures for waste reduction before, during and after construction activities. An integral CDW management plan includes the development of a waste management report (in the design stage) and a site waste management plan (in the construction planning stage) (Jiménez-Rivero et al., 2017).

- *Construction*

Esa et al. (2017) highlights the adoption of site waste management plans (SWMP) as the main strategy influencing the stage of construction and building renovation. In this stage, the amount of waste produced depends on the type of management. Thus, inefficient management practices imply larger volumes of CDW. The design and implementation of a SWMP is considered an effective strategy to improve CDW management operations, and it is applied in any construction and renovation activities, even in the end-of-life stage during demolition and deconstruction activities. Like CDW management plans, the adoption of a SWMP provides opportunities for waste reduction and for increasing the rates of recovered materials. These models identify and estimate the waste types that will be produced and provide a detailed plan for waste management (López Ruiz et al., 2020). Proper collection and segregation techniques facilitate the preparation of CDW for reuse, recycling and other recovery alternatives, this techniques must be identified in the SWMP and be available to all relevant actors (López Ruiz et al., 2020).

To further improve the use of resources and the reduction of waste in the construction stage Migliore et al. (2020) suggests also using building products with low material content and low embodied energy, and using building material derived from secondary material, obtained through recycling processes.

- *End-of-life*

The end-of-life stage is characterized by high volumes of CDW, the highest in the entire lifecycle of construction activities. There are two general practices in this stage: conventional demolition and selective demolition or deconstruction. In this stage, the opportunities for material recovery depend on the type of demolition technique that is used and the type of building (Schultmann and Sunke, 2007).

Douglas et al. (2019) describes deconstruction as the systematic dismantling and removal of a structure or its parts, in the reverse order of construction, for maximum value through the salvage and harvest of components, primarily for reuse in their original purpose and secondarily for recycling. Deconstruction presents a valuable alternative to traditional demolition and involves the disassembly of buildings to recover the maximum amount of reusable materials. It employs the key CE principles of designing out waste and keeping products and materials in use, bringing clear environmental, social, and economic benefits.

Some of the benefits of commercial deconstruction described by Douglas et al. (2019) are environmental, resource conservation, carbon reduction, decreased landfill volume, economic, reduced tipping fees, strengthened local economy and job creation, materials kept at highest value, social, green workforce training, creation of local jobs, and respect for history of communities.

Presently, deconstruction is underutilized due to barriers related to data, process, reuse markets, regulatory frameworks, and technical know-how. In order to enable deconstruction and salvage of valuable resources from commercial buildings, design build teams and municipalities can begin to take steps that improve the permitting process and experience, incentivize the right enablers and actions, and support project process and infrastructure that nurtures reuse of salvaged materials from commercial buildings (Douglas et al., 2019). Engaging a demolition contractor early in the process enables value to be extracted and shared between the client and demolition contractor (UK Green Building Council, 2019).

Pre-deconstruction/demolition audits, also referred to as waste audits, represent an enforcement measure for minimizing waste from end-of-life activities. This practice allows the planning and implementation of more efficient waste management strategies and maximizes the volume, quality and potential saving costs of recovered materials, while it reduces waste generation (Jiménez Rivero et al., 2016). They should identify the volume, quality, recovery rates and location of the range of materials expected to be produced during demolition or deconstruction activities (López Ruiz et al., 2020).

- *Material recovery and production*

The recirculation of recovered resources in the life cycle allows their use in the production of new building materials, while avoiding the use of virgin raw materials. This leads to environmental benefits such as energy savings and a reduction in the use of natural resources and pollution (Yeheyis et al., 2013). López Ruiz et al. (2020) emphasize four strategies as the most influential in terms of waste management of CDW and its future recirculation in construction projects: (i) reuse, (ii) recycling, (iii) energy recovery and (iv) backfilling.

Reuse strategies consist of using harvested materials, construction elements and building materials again to meet their original or a different function (Huang et al., 2018). Thus, materials and components can be directly reused or can require little reprocessing through the application of three actions (Schultmann and Sunke, 2007):

- Repair is focused on returning used products to working conditions and is limited to assembly and reassembly of fixed parts.
- Refurbishment consists of improving the quality of used products by simple actions of disassembling, inspection and replacing of components.
- Re-manufacturing is aimed at providing quality for used products, according to specific standards which are as rigorous as those for new products.

The application of *recycling* methods is a fundamental strategy in CE, as the use of recycled content in the manufacturing of construction materials has environmental benefits over the use of raw materials. In addition, it constitutes a principle way to reduce CDW disposed of in landfills and the demand for natural resources. Furthermore, it reduces the energy consumption of manufacturing processes for the building industry (Huang et al., 2018).

In a general framework, recycling treatments can be applied through three typologies according to Huysman et al. (2017):

- Closed-loop recycling, in which the salvaged material can substitute the original virgin material in a 1:1 ratio.
- Semi closed-loop recycling, in which the salvaged material can partially substitute the original virgin material, but raw materials must be added to comply with quality requirements.
- Open-loop recycling, in which the salvaged material is used as a partial substitute in the manufacturing of different materials

Energy recovery can be applied to materials with high caloric potential (e.g. wood and plastics) by incineration to produce energy that could be reintroduced into the system and used in power plants and heat delivery centres (Huysman et al., 2017).

Lastly, CDW can be used as a substitute for natural resources for *backfilling* embankments. This is a common practice for materials such as recycled aggregates produced in large demolition works, where

demolition waste is crushed and used to fill open sky cavities (Coudray et al., cited in Gálvez-Martos et al., 2018).

- *Circular Procurement*

As previously mentioned, supply chains in the construction industry are of high complexity, therefore the procurement process is of great importance. Laffont and Tirole (1993) define procurement as the process of finding and agreeing to terms, and acquiring goods, services, or works from an external source, often via a tendering or competitive bidding process. Based on that, and other similar definitions, Salmenperä et al. (2017) propose the following definition of *circular procurement (CP)*:

"The procurement of competitively priced products, services or systems that lead to extended lifespan, value retention and/or remarkably improved and non-risky cycling of biological or technical materials, compared to other solutions for a similar purpose on the market" (Salmenperä et al., 2017).

Circular Procurement is part of green and/or sustainable procurement aiming at value creation, social well-being, and environmental improvements through closed and safe material loops (Salmenperä et al., 2017).

Salmenperä et al. (2017) have listed four different approaches that can facilitate these closed loops. They are summarized in the following figure:

Better quality products	*Procurement of improved products and services by adding "circular criteria"*	These can include criteria for recyclability, reuse of materials, use of recycled materials, etc. this may be considered the simplest way or the first phase of buying in a circular manner.
New products	*Procurement of new and innovative products, services, and materials promoting CE-based businesses*	This means products that are considerably better in terms of recyclability, recycled materials, disassembly, long lifespan, and can stimulate innovative solutions. It often involves products that are new to the market
New business concepts	*Procurement of services and new business concepts*	Focuses on the procurer's need rather than on the product itself. These include product-service systems, leasing concepts, shared use, buy-per-use, and take-back schemes.
Circular ecosystems	*Procurement promoting industrial symbiosis and circular ecosystems*	This approach addresses large investments and the creation of ecosystems that call for commitment from different stakeholders. Circular ecosystems could be efficient platforms in supporting closed loops and creating networks in which the waste from one actor would be used as a raw material for another.

Table 2. Four approaches to Circular Procurement (abbreviated from Salmenperä et al., 2017).

- *Adaptive Remanufacturing*

The office is home to a vast range of resources, from the fabric of the building (ceiling tiles, plasterboard, glass, etc.), to the fittings and furnishings (carpets, desks, chairs, IT equipment, etc.) and items used on a regular basis (paper, food, drinks, uniforms, etc.) (Business in the Community, 2018). These need to be considered also if higher circularity is to be achieved. In this vain, servitization and remanufacturing have been chosen as the optimal CE principles. Servitization represents a transition

from selling products to selling services. A payment structure must be established through which customers have unlimited access to resources but only pay for what is used, or the result linked to their use (UK Green Building Council, 2019). Remanufacturing then involves returning a previously used product to a level of form and function effectively equivalent to when that product was new. In some cases, remanufacturing can upgrade a product to condition beyond its original state by, for example, correcting for original product design flaws or adding functional or aesthetic enhancements not found in the original product. Several studies demonstrate that remanufacturing operations consistently achieve energy savings, cost savings, and increased material efficiency relative to new products. The fundamental premise of remanufacturing is that it extends the life of a good in the product stream, maintaining its value (Boustani et al.; Abbey et al.; Babarenda Gamage et al.; Bakker et al., cited in Krystofik et al., 2018).

Adaptive remanufacturing, on the other hand, suggests the use of an end-of-life product core to create a similar but non-identical product whose function and use characteristics are effectively equivalent to the original new product. It maintains the original product's function in the same application, but may change its form, configuration, or construction in order to establish functional equivalence with contemporary virgin products (Krystofik et al., 2018).

As described by Krystofik et al. (2018), *adaptive remanufacturing* enables remanufacturing designers to update, reconfigure, and customize previously obsolete products to meet present market demands. In this, remanufacturers can avoid the risk of obsolescence and continue to utilize the product's embodied value until loss of material integrity affects the economic viability and environmental preferability of further remanufacturing. Ultimately, this possibility creates the potential to extend product life beyond what is possible with traditional remanufacturing.

3. Research Strategy and Method

In this chapter the research strategy chosen, and methods used are described.

3.1 Research Strategy

The research strategy is a qualitative case study aimed at exploring and understanding how resources and waste are managed in the case study company and what are the opportunities for improvements.

The initial stage of the research methodology consisted of a thorough literature review centred around key words such as “construction and demolition waste”, “circular economy”, “building sector”, “real estate”, “business model”, and the combination of them.

The empirical data is based on semi-structured qualitative interviews where the information gathered was consolidated in Chapter 4 to offer an image of the status of the case study company regarding the research questions.

3.2 Method

The first step of the method process was an initial literature review on the chosen topics with the aim of formulating the research questions. Upon defining the research questions the subject of the case study was chosen, Castellum. A more comprehensive literature review followed to collecting as much information possible to aid in the answering of the research questions and fulfilling the aim and purpose of this paper. The literature review was also used to formulate the interview questions.

The second step was conducting the interviews with interviewees chosen for their relevance to the topics at hand, the company’s business processes and sustainability efforts. The interviews with Castellum’s employees were conducted with the manager responsible for sustainability for region West (Paula), the development chief for region West (Tobias), project manager (Leonardt) responsible for the renovation and development of new buildings and an online talk followed by an interview with the head of sustainability (Filip). These interviewees were chosen to give insight into the company’s main business activities and their sustainability efforts.

The project manager (Leonardt) was chosen to answer questions about the company’s business processes around the renovation of offices and new build, as he has years of experience working with this. The sustainability managers (Paula and Filip) were chosen to answer questions regarding business processes on an organizational level, and questions regarding the company’s sustainability efforts, while the development chief (Tobias) was chosen to answer mostly general questions about the company and its business model.

Additionally, relevant stakeholders to the research where also interviewed: a representative of the municipality (Åsa), a researcher from RISE with expertise in CE and CP (Emanuela), and an expert in CDW recycling working at Stena Metall (Mats).

The interviews were conducted in person, or online. After the interviews were conducted, they were transcribed, summarized, and organized in this following chapter. The interviews were conducted in English and none of the participants had any objections of being named in the paper, or having their company named. The data is thus not anonymized, and the participants are addressed by only their first name. Castellum’s Year End Report and Sustainability report were also analysed.

The following step was the analysis of the data, both empirical and theoretical. The analysis was based on Hennink et al. (2011)’s five tasks: description, comparison, categorization, conceptualization, and explanation. These were used interchangeably to answer the research questions. They are described below:

Task	Description
Description	Forms the foundation of qualitative data analysis and provides the rich detail that is sought in qualitative research
Comparison	Defining and exploring issues and notice patterns in the data
Categorization	Involves grouping codes with similar attributes into broad categories
Conceptualization	Involves visualizing the data to develop a conceptual understanding of the issues
Explanation	Provide a broad conceptual understanding of the phenomenon studied

Table 3. Tasks for data analysis (derived from Hennink et al., 2011).

A qualitative analysis of the relationship between theory and empirical data was performed on the assessment of CDW management practices. Challenges, barriers, and opportunities for CDW were derived based on inductive reasoning. This was intended to give a sharp image of the status of the company regarding the topics at hand. A stakeholder analysis was performed based on the empirical data gathered from the interviews with the same purpose in mind. The analysis was limited by the data acquired from the interviews, as only four members of the company were interviewed.

The final step of the analysis, called *Recommendations* in this paper, was created by combining all the data gathered from the literature review and the data from the qualitative analysis of the empirical data derived from the interviews to provide the best fitting solutions for Castellum today. The discussion and conclusion chapter summarizes the key findings, discusses the implications and limitations of the findings, and offers the authors' interpretation of them.

The research was performed in the most ethical way possible and all the interviewees gave their permission to have their names used. The trustworthiness of the data presented is based on the triangulation of the different responses to the same interview questions. As the matters researched regard mostly business processes, the authors do not see any ethical ambiguity around that, nor do we hold anyone specifically ethically responsible for the performance of the case company. We are aware that a shift to Circular Economy will entail changes in the supply chains, which may result in certain jobs disappearing while new ones are created, but we also feel that the overall benefits of CE outweigh the potential downsides.

The primary topic of the paper: construction and demolition waste, is seen as the highest contributor to the industry's environmental impacts in most of the literature reviewed. Thus, sustainability is an integral topic of the paper, as the aim of paper was to improve the management of waste at the case study company and contribute to the overall sustainability of the industry. The ethical implications are seen by the authors from a biocentric perspective where the efficient management of resources can contribute to a sustainable future and reduce the environmental impact and climate change. The Thesis was conducted in a joint effort between the authors and the work was equally divided.

4. Empirical data

The empirical data chapter is aimed at presenting the results of the qualitative research. It offers an overview of the company's practices, performance, goals, and aspirations on the research study's topic, along with the data collected from the stakeholders outside the company. The data presented here is, along with the theoretical framework, the basis of the analysis and given recommendations.

4.1 Castellum

Castellum is one of the largest real estate companies in Sweden with properties spanning across 4.3 million square meters, valued at around 95 billion SEK. The portfolio consists of offices, warehouse/logistics and public sector properties. They own properties in many cities across Sweden, Copenhagen, and Helsinki. Their office portfolio represents 47%, 23% public sector properties, 16% warehouse/logistics, 8% retail and 2% light industry, while the remaining 4% is projects and undeveloped land.

Castellum's customer base consists of various tenants as shown in figure 2:

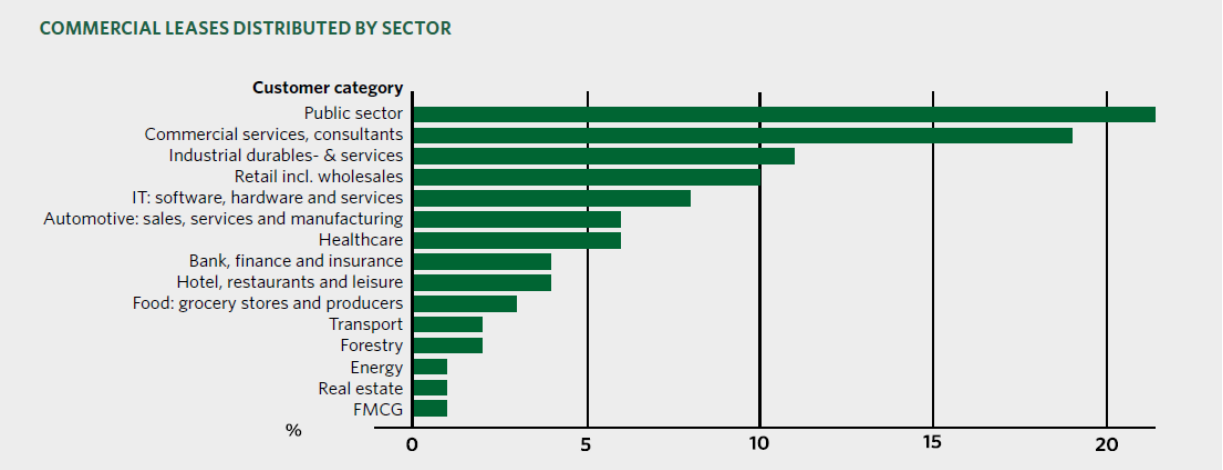

Figure 2. Commercial leases distributed by sector (Castellum, 2019).

4.2 Castellum's practices

The interviewees all agreed that the key driving factor for the company's success is its long-term vision. *"We build to own, not to sell, we think of it as part of our portfolio for the next 50-100 years"* Paula said. Other key factors pointed out were customer relation, sustainability strategy, daring to take risks, new technology, and big investments (like the buying of the old Säve airport, which is to be transformed into a large logistics hub). The company's main value proposition consists of offices for both the public and private sector, logistics centres and warehouses.

Castellum´s efforts are aligned with sustainability trends such as *1) Climate Resilience and Risk Management, 2) Circular Economy, 3) Energy Self-sufficiency and 4) Social and Health Wellbeing in Buildings* described by Filip: "*We have our climate target and to get us there we must accelerate and intensify the use of circular materials, and rethink the material flows, especially in renovations and construction"*. On the matter of the biggest risks to the overall business the company is facing, the interviewees consider them to be the development of logistics centres as it is a fast changing industry, the use of new technologies like VR (virtual reality), developing new buildings on speculations (without

tenants attached to it) and risks of climate change impacts on their properties. They all agree that the office business, new and renovations, pose a much lower risk, as there is a high demand for those, especially in central Gothenburg, Stockholm, and other larger Scandinavian cities.

The company has had sustainability goals in many different areas since the mid 90´s, and they span today across energy use, use of chemicals, water use, but not on the matter of waste, *"even though it is a big issue for us"* as one interviewee claims. There have been certain efforts at the company to increase the circularity and the use of circular materials, for instance in reusing different building materials, or reusing office furniture, but no full company strategy yet. Top management and shareholders buy-in into matters of circularity has been characterized as high by the interviewees. But since they, and the whole industry, is starting to realize that the building process is a big waste source they want to perform better on that front:

"When it comes to waste, one of our core activities and what we do every single day is office renovation which generates a lot of waste and we are responsible of it, we have no goals yet for this, but we will get there." Paula

Castellum performs annual sustainability educations structured in digital modules for all employees which they must go through, additionally personal trainings with specialists in different fields are also conducted. The education is built around external and internal aspects. The external revolve around documents such as the UN´s *Sustainable Development Goals* and *Global Compact*, environmental certifications, ISO standards and other applicable laws and regulations on the topic. While the internal ones consist of the Castellum´s sustainability policy, code of conduct, internal environmental management system and other internal instructions.

As the office, and not logistics centres, or warehouse, were chosen to be the focus of this study, the rest of the interviews deals solely with them, building of new offices and the renovation or old ones, for existing tenants or new ones. Since these vary greatly in size, price and scope, different approaches are taken when conducting them. For smaller projects, like smaller renovations, the company has a roster of suppliers that they can hire easily without a tender process to do the work needed. When it comes to bigger projects, the project goes through a tender process. The tender is given to the company that offers the best price, but criteria like *"sustainability and capacity"* are also considered, although no data on specific examples were given.

A. The project processes

The pre-assessments process is done in-house, by a team consisting of building engineers, carpenters, and other experts for the field. This is common practice for new built and large renovations. They evaluate the properties purchased, review the city planning, and make project proposals, that are then sent to the rental department that works on finding tenants for the new building. When they find enough tenants for the potential building, the project starts rolling. The team responsible for project development at the company consist now out of 10 people, who cooperate together on this stage of the project in order to plan the project to the best of their abilities and share knowledge acquired on previous projects.

When it comes to office renovations, the procurement process usually happens in the following way: the client (tenant) requests it through the building manager, it can be any of a number of things, they need more space because they are growing, or less space because they need to reduce the staff, or just want a renovation because they feel the office is due for one. The last one depends highly on the clients in questions, as Leonardt, the project manager, put it *"on the fifth floor* (of one of their office

buildings in central Gothenburg) *it's lawyers, and they change their offices every three years. That is not sustainable, but still, they do want to do it and we cannot really say no, if we say no, they are going to move,"* this sets of in motion the renovation process. As mentioned before, for smaller renovations the company can select one of the frequent suppliers and ask them to make an offer, for larger projects a tender process is common practice. That means that new projects (new building) always go through tender process, while renovations can often be done with a smaller supplier.

"If it is a small project we can manage with smaller contractors. But when it comes to larger projects, maybe where the client has an architect, we work with the contractor and they subcontract demolition companies. We normally contract under design-and-build, so they make those decisions. For smaller projects we set the contracts ourselves, but for larger projects we realize tenders." (Leonardt)

For new projects, the tender process is common practice, as in most of the industry: the company does a proposal of a project, releases the tender, then awards the contract to the contractor with the best offer. The most common contracts they use are design-and-build contracts, lump sum (fixed price) and target contracts (pain-gain is shared among the company and the contractor).

For new offices, or bigger renovations, architects/designers are hired, most often through a tender process. For old buildings that the company owns, if a demolition is needed, the process is the same: the company puts out a tender so that the demolition companies compete for the project. The same applies for bigger renovations of existing offices.

When asked about the influence and environmental requirements by Castellum over partners along the value chain, Paula mentions both scenarios where some seem more interested to new ideas and others more reluctant, she mentions a recent *"flood of news"* that could sway the whole industry, "*I am really optimistic about that and I do not think that is a big problem* (to influence them)*."* A good way of collaboration in the beginning of implementing new processes is through partnerships since everyone is new to these ideas, both Castellum and their business partners can then learn in the process and after a few years it starts becoming a demand.

The company has attempted to put requirements on contractors doing office renovations to use a certain percentage of circular materials, and to achieve a certain rate of circularity, but since they have no real way of measuring this rate, the success of these measures is unknown. They have recently started implementing a new tool called *One Click LCA*, in cooperation with IVL Svenska MIljöinstitutet, where one can register all the materials used and get measurement of circularity which they hope will help, but since there is a lack of standardized methods to measure circularity it will still be hard. "*Setting up a demand is easy but measuring it and seeing that we get this is the tricky part." (Filip)*

When asked about the ratio between projects for new building and remaking of existing ones, the rental department put it at 10%-90%, which makes *"remaking and refurnishing of existing offices for tenants the main process for us"* (Leonardt). These vary from small refurbishing (like the changing of carpets, or repainting) to big projects (like building and adjacent building next to an existing one because the client's business has grown).

How often the offices get remade depends solely on the client/tenant. Certain clients do these things on their own, which they can do, although the interviewees did not specify which small works the clients can do themselves. But, for larger renovations the company must be contacted. These renovations vary from small to large, from shorter time periods to longer, but on average, as one of the interviewees estimated *"every 3-4 years they request a small touch up",* like repainting, changing of carpets, partitions and similar.

"I think that most of us, that have been in sales or similar, know that you cannot really say no to a customer, it doesn't matter how small it is." (Leonardt)

Castellum has a big portfolio, around 6.000 different tenants and their strategy is commercial tenants. Private offices consist of approximately 1,6 million sqm out of a total of 4,25 million sqm of Castellum´s portfolio (Castellum, 2019). Customer loyalty creates value for the company, as one interviewee said. Which makes the customer request the main driving force for the processes implemented by the company. These requests that customers make regarding the design of the office, can vary greatly, depending on the client again. Some bigger companies even have manuals that detail how their office should look like, the smaller ones are usually more open to variations, then Castellum can make proposal for them. "*So, it depends solely on the tenants, but we are always happy to help them decide…"* which design to choose, a project manager said. The head of sustainability at Castellum thinks that the office tenants, and specifically those located in the CBD area (central business district) are usually the ones more interested in sustainable solutions. There is also a correlation between bigger companies that usually have bigger demands when it comes to sustainability and are more willing to compromise for sustainable solutions.

As mentioned previously, Castellum does not have internal waste goals, which reflects in their procurement process, as it does not contain any sustainability criteria regarding the reduction of waste or better waste management practices than legal requirements. This means that the management of waste is left over to the suppliers – contractors and demolition companies. The only recognised activity on this matter in the company is internal efforts to reuse certain materials and products. The company owns a warehouse where they store used materials, furniture and supplies ready for reuse. All of our interviewees claim they try to find a use for these and they try to convince clients to use them in their rented spaced, often combined with cost savings, as the items saved are neither old, nor in bad shape, as long as they comply with the required standards and contain the appropriate markings. The savings can be significant as Leonardt illustrated: *"That* (used door) *will cost 2000-3000 instead of 20.000 for a new door."* The company is currently cooperating with IVL Svenska Miljöinstitutet and Business Region Gothenburg in an effort to produce metrics that will be able to show the environmental benefits of these reuse processes, but they have none so far and their performance is still on the level of voluntary effort by the managers. They hope that metrics like these, plus the cost savings from reuse, will be enough to convince the clients to always go for reused materials instead of new ones. They have also received positive feedback on this from architecture companies that they cooperate with as "*they see it as a real challenge to mix old stuff with new stuff. Instead of drawing up a typical office, they get a challenge of taking something old and making it look new again."* (Leonardt)

A challenge for reusing materials is the lack of time and planning, when describing the process of projects, "*Nothing happens for a long time, and then when it happens, it happens so fast. And then it is too late to come in and start discussing the design and the use of reused materials since we do not have the structure yet…we need to find a structure, like a checklist, and on it there should be to think of reused materials."* (Paula)

The interviewees have shown initiatives to introduce in the company new sustainable solutions, mostly regarding the reuse of materials and products from demolition in new projects (both renovations and new built), such as *the Återbruk Väst* program and internal reuse initiatives. This is done in a relatively unstructured way, but a tendency to have it implemented on a larger scale has been recognised. The project managers in the company are constantly, according to the interviewees, looking at waste produced and trying to find ways to reuse it, and convince the tenants that to accept these in their rented spaces. They do encounter obstacles with reuse, for instance if doors are lacking

markings, or steel beams are corroded, which make reuse hard or impossible, as it does not comply with construction rules and regulation, or with the requirements for environmental certificates. When faced with such obstacles, they tend to opt out of reusing, meaning, they only try to reuse products if they are certain they will be able to do so.

The biggest problem with the use of circular materials, in the view of the head of sustainability is the lack of a market for these. "*What we are struggling with is the market, it is quite easy to set up these targets for development, but when it comes to the reality and when we are contracting, it is not that easy."* (Filip) In order to achieve a higher level of circularity Filip feels that effort need to made on both sides, Castellum's and the market side: "W*e have to set up a better strategy, but we are not really able to do that before we feel we have a market in place on the other side, and there will be no market in place on the other side until we set up these demands."*

B. The design and construction

Even though Castellum's project managers work closely with architects/designers from an early stage of the project, they do not take waste into consideration. Paula believes that when they start working with "*architects and contractors who are interested* (in the topic of waste reduction)*, … in a collaborate way"* they will be able to change this and consider the waste generated. As a part of the company's strategy to own all their documentation they request BIM models from the architects designing the projects. They use the BIM models both for design, but also for VR for clients and tenants, as a part of a sales pitch. The interviewees see these BIM models as a potential for having logs of materials used, dimensions, colours, structures of walls, and similar that they could use for both pitching to potential clients, and logs of materials available for potential reuse. That is currently still very small scale, as they only have BIM models for *"small percentage of buildings we own".*

When asked where they see the most unnecessary waste being created the interviewees named several areas:

1. Human error, like wrong ordering, mishandling of goods, misplaced good… *"I think that in every project I finish there is a big pile of construction material standing in the corner unused"*
2. Faults in design that lead to excessive ordering
3. Difficulties with sorting waste on site if there is not enough space on the site

The contractors are the ones responsible for on-site waste separations and the disposal of said waste, and they (the contractor) are the ones who measure the waste amounts and waste sources. They have it calculated in their budgets and that constitutes a part of the price of the project. It is then in their best (financial) interest to separate it in the best way possible, as it is cheaper to dispose of separated waste, than mixed, while some fractions, like metals, can be sold for profit. To keep track that the contractor handles waste in the best way possible, Castellum performs ocular inspections on site and keeps tracks of the receipts from the waste disposal centres, but seldom put specific demands on contractors beyond the maximum amount of waste allowed to be disposed of in landfills. They do this even though it *"is unnecessary since most of the time it will be even more expensive for them if they do not separate it."* (Paula). The most common types of contracts with the contractors are fixed-price contracts, where Castellum tends to set demands sometimes, sustainability ones among them. One example of this is given further down in the text.

Regarding the materials used in construction for their projects, the interviewees say that that depends a lot on the manufacturer, the company does not take much responsibility for it, even though they have started making attempts to source more recycled materials instead of virgin ones. "*We are not*

a manufacturer, so the big emissions from our sector is development, 98% of our emissions. And the big emissions in development come from materials, so that is our focus." There are some recycled materials used, but the data on that is unavailable to the company, and it is something they would want to see more of: how the materials were sourced, how much were they transported, what percentage of them is recycled material: *"We have no control over the building materials, how it's made, processed, what percentage is recycled. I would like to know that."* (Leonardt)

The personal opinions of the interviewees all agree that is should be cheaper to be environmental, but that that is not the case today, "*it's still cheaper to be a bandit when it comes to bad materials"* (Leonardt). Some initiatives in this direction that Castellum is taking is building more wooden house and carbon neutral houses, which are still in the pre-project state at time of writing of this report. They believe that by doing so, they will be able to contribute to lowering the prices of more environmentally friendly solutions, which would make them more common practice.

C. Use and demolition stage

When building new buildings, Castellum uses Miljöbyggnad environmental certification almost as a rule, or an alternative one like BREEAM. None of these certificates take waste generation or resource use into great consideration but focus more on the use stage performance of the building.

When it comes to the furniture and equipment in Castellum's offices, they are not the ones who own it, according to our interviewees. They have had discussions with a large Swedish furniture manufacturer about a possible partnership of leasing furniture, but that has not been realised yet. The company does cooperate with several companies in Gothenburg that refurbish used furniture and sometimes buys them from there if the client/tenant is receptive to the idea. That does not benefit the company financially, but they do it to try to reduce their impact. Although no specific strategies are in place for furniture, they *"are looking into some new models where we can lease the furniture out in fully furnished offices".* As this large Swedish furniture company is not yet ready for this kind of leasing of furniture, Castellum is attempting to do it themselves, with the help of some architects and interior designer they cooperate with and are thinking in the same direction, but it is not likely to happen in the first stage since it might be too big of a project. Although they have an ongoing pilot project in Helsingborg where they will lease out a fully furnished office with circularity demands (Filip). For the time being, also, Castellum has only tried to act as a connection between companies that remanufacture used furniture and tenants, without taking ownership of the furniture, in order to support sustainable businesses, not increase their own level of sustainability.

"We are hoping, in the future, to be able to lease out fully furnished offices, made from reused furniture, among others." (Leonardt)

Castellum is also a part of the *Återbruk Väst* programme, which, according to Paula, aims to make it easier for companies to reuse materials and for real estate companies to create a network. *Återkbruk Väst* is a collaborative arena between property owners, architects, public sectors, and researchers trying to find ways to scale up reuse in the construction sector on an industry level by creating and legitimizing a reuse network. This would alleviate the difficulties connected with communication issues and knowledge transfer. Although the project is ongoing "a*t Castellum we are still immature at this, so we are testing it at a smaller scale before we share it in the platform"* Paula said. The big challenge for the platform, according to Filip, is reaching a certain number of users to make it more effective and useful, and reaching a certain quantity of materials and sorting out the pricing system.

The demolition is usually delegated to the contractors. Castellum does not tend to put any specific demands on this part of the process beyond the legal requirements, but exceptions are possible. One such example involved Castellum asking a contractor to disassemble 17 glass partitions and transport them to Castellum's internal reuse warehouse. Despite the contractor advising against it, as they did not believe it would be portable, Castellum went through with it. The partitions cost (when new) 160.000 SEK and the price of dismantling and transporting them was 26.000 SEK. At the moment of writing of this paper the partitions were still in the warehouse but were very likely to be used soon in a new project for a tenant who wants reused products, so Paula sees this as a success story. When doing demolition before renovations, or for worn down buildings, Castellum's project managers tend to mark for the demolition companies the items they want save, to reuse them. So, these demolitions are performed as a sort of selective demolition usually, which mostly has to do with the fact that that way the disposal of waste becomes cheaper, if it is properly separated. "*I would say it is not too complicated to use a selective demolition method, you just need to be more careful handling it and packaging it. You need to convince the demolition companies you will reuse that material. We need to find the right people to work with, it is going to make it easier for us" (Paula)* and make time in the project process for this.

When asked what she sees as the crucial social condition for promoting CDW reuse and recycling Paula said "*We not only need to find partners like architects, contractors, and demolition companies, but also clients who are positive and interested in this. We need to be able to communicate how much impact we avoided by doing this. We also require enough material to use in the project."* She also emphasized that is should be default for the sales representatives to promote reuse and recycling to clients, as a means of acquiring goodwill and brand reputation. Because, no matter how much effort the company puts in internally in these matters, if they cannot sell it to clients/tenants, it will be fruitless. Since reuse strategies are still performed on an unstructured level, it was difficult to obtain any concrete examples used in the company, besides the few already mentioned in this chapter.

4.3 Stakeholders

Interviews with stakeholders within the CDW and CE fields were conducted with the aim of understanding the external context of the value chain.

Circular Procurement and Financing expert suggested that "*when it comes to the construction industry, the design stage is the most relevant one. There, the basis for circularity within the built environment needs to be set."* (Emanuela, RISE institute)

According to Emanuela circularity standards represent an essential aspect for transitioning into a CE. Several institutions and organizations are adding efforts to develop them, *"there are standards for circularity being developed by ISO as well as the British Standard Institute. ISO 14001, the environmental management standard is the closest to it so far…"* Regarding certifications, the Nordic Swan Ecolabel seems to outreach similar targets as it pays great attention to materials, their source, environmental impact and level of recyclability.

On the procurement matter *"Public Circular Procurement and Private Circular Procurement are not comparable"* mainly due to the different regulation models. Within the (Swedish) National Public Procurement Strategy is considered Green Public Procurement and where under Circular Procurement is mentioned. Some of the common circularity measurements considered in the procurement stage nowadays are life-cycle analysis and recyclability. Emanuela also pointed out recirculation, utilization, and longevity as potentially becoming standards.

When discussing about the biggest challenges and opportunities Circular Businesses face, the lack for a standardize CBM, adapting the revenue model, value creation, value proposition and changing customer relationships appear to face the riskier ones according to Emanuela. Another interviewee working as an environmental inspector for the municipality (Miljöförvaltning) pointed out *"... there is not a big market for recycled materials, there is an economic aspect as well. A lot of rules that you must follow to recycle the materials, that slows down the market. You need to have a balance; it is a national issue."*

Some of the key aspects that can increase the recycling rates of materials according to CDW expert Mats currently working at Stena Metall are early planning, information about contamination and communication, "*…demolition consultants increase the recycling rates definitely, the more you know about an object before you can demolish it the more value, but of course sometimes you make a balance and see how much did I gain from it and for a small object maybe you don't get the money back, the more data you have the more overview you get the more you can get the recycling rates up."*

While the main hinders represent lack of guidelines and taxes on raw materials from governmental bodies, *"…there is nobody that "puts the foot" and say this is allowed this is not allowed, in Sweden. You see it better in other countries like Denmark or the Netherlands where you say how things can be used. In Sweden is up to every local authority at the municipal level to decide what is going to happen and then with those rules, which could vary from the next person coming in the municipality it's really hard to build a consistent case business and get it going."* (Mats)

5. Analysis

The analysis of the data is aimed at answering the research questions and fulfilling the purpose of the paper, and it is based on the theoretical framework and empirical data. It is divided into four sections, covering the four research questions. It covers the tasks of description, comparison, categorization, conceptualization, and explanation. The description of the findings forms a basis for further analysis, and it covers the management of resources and waste at the case study's company. The comparison is aimed at finding similarities and discrepancies between the case study's company and the industry standards, practices, and trends, described in the theoretical framework. Categorization and conceptualization serve the purpose of making sense of the analysed data so an explanation and recommendations can be offered in the end of the topics researched.

5.1 Construction and demolition waste

The first subchapter of the analysis aims to answer the first research question:

- RQ1: What is the status of resource use and CDW management at Castellum?

The construction and real estate sector are major producers of waste in the EU, consume a lot of resources, and create serious environmental problems during the entire lifecycle of buildings (Deloitte, 2017, López Ruiz et al., 2020), so it comes as no surprise that Castellum is dedicated to their sustainability agenda, which includes becoming climate-neutral by 2030 throughout their entire value chain (Castellum, 2019). This includes now environmentally certifying all new projects, reducing water consumption, energy, and emissions in the use stage, but will little consideration of the resources use and waste generation in the construction and end-of-life stage. In line with this, the European Commission (2020) recognises circularity as an essential part of a wider transformation of industry towards climate-neutrality and long-term competitiveness.

The associated environmental impacts of the construction sector as described by López Ruiz et al. (2020) of land degradation, greenhouse gas emission, high energy consumption, and resource depletion are aligned with Castellum's sustainability efforts of climate resilience, energy self-sufficiency, and water use. As the industry is characterized with long life cycles of products a long-term strategy is crucial for real estate companies, something that Castellum recognises with their vision of creating a portfolio for the next 50-100 years.

As several authors showed (López Ruiz et al., 2020, Josephson and Saukkoriipi, 2007, Kirchherr et al., 2017) the construction and real estate industry does not perform well in the areas of resource efficiency and waste minimization, and Castellum is no exception, as they still do not have sustainability goals concerning waste generation and are responsible for the generation of significant quantities of it. Due to the fact that an approximate of 72% of the total greenhouse emissions and 50% of the total energy consumption of an office building comes from building materials (Eberhardt et al., 2019), and offices constitute the largest portion of Castellums value proposition, they were chosen as the subject of our research and analysis. Castellum acts as the owner and investor, as they are a real estate company.

Figure 3 represents the general project process gathered from the empirical data, the process is driven by the client requirements which varies depending on the complexity and scope of the project leading to the procurement strategy. Castellum often hires the main contractor under *totalentreprenad* which means they are responsible for the design and the execution of the project adhering to Castellum´s criteria. In this case the main contractor is responsible for the pre-demolition audit where normally

only the minimum legal requirements are fulfilled. Only few contractors develop a CDW management plan, which is rarely standardized as it is not a binding requirement from the municipality. As CDW management plans have been identified to provide opportunities for waste reduction and increasing the rates of recovered materials (López Ruiz et al., 2020), this is perceived as missed opportunity.

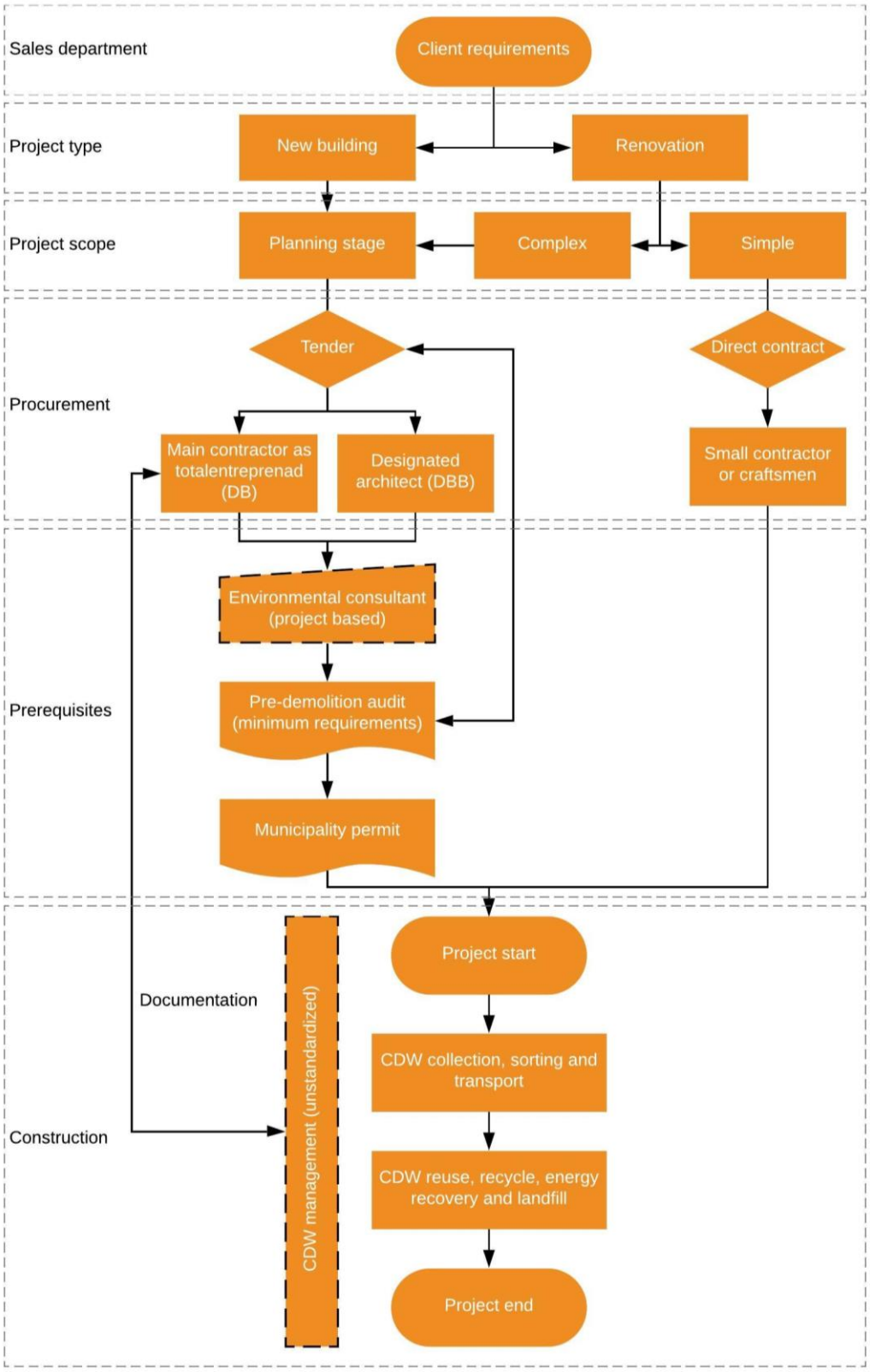

Figure 3. General project process as Castellum.

Office renovations are a big part of the company's everyday business, while the building of new office buildings is also present, but in a smaller degree (the ratio is roughly 90%:10% in favour of renovations). The project process is similar for larger renovations as for new buildings and relies mostly on the tender process, while smaller renovations are done mostly on partnership contracts with known suppliers. This poses two different opportunities for improvement, as the procurement process (tender) and partnership contracts describe different relationships among stakeholders. The tender process depends mostly on price and fulfilling the requirements specified, while partnerships open the way towards collaborative input. So, when it comes to construction work, Castellum serves as the client.

In order for real estate investors and construction clients to integrate CE as an inherent part of their business strategy some main principles need to be introduced, like designing out waste, keeping products and materials in use longer, and regenerating natural systems (Acharya et al., 2020) and in order to do so Castellums business process is divided in stages, as shown in Figure 3, including the design, construction, use, and demolition as these differ in their performance, impact and possible solutions, and comprise the company's business model.

5.2 Challenges, barriers, and enablers

The second subchapter of the analysis aims to answer the second research question:

- RQ2: What are the main challenges, barriers, and enablers in improving resource use and CDW management practices of Castellum?

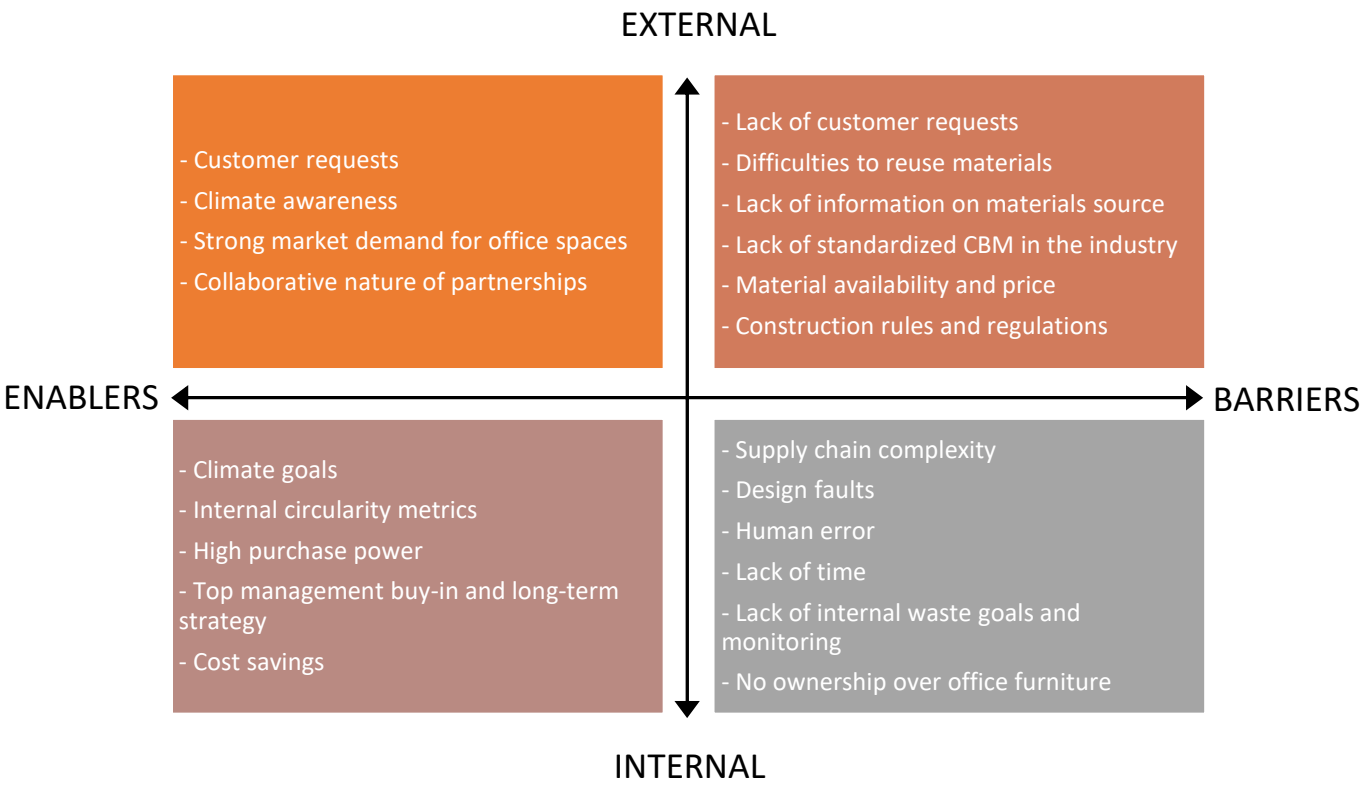

Figure 4. Barriers and enablers for implementing CBM.

The barriers, enablers, and challenges in improving the waste management at Castellum based on CE are derived from the empirical data and related to the theoretical framework chapter. They are summarized in Figure 4 as internal and external barriers and enablers and described in the following text:

Barriers:

The first recognised internal barriers concern human errors, like the mishandling and misplacing of goods, and faults in design that lead to excessive ordering, the quantity of which varies project to project. This creates materials that are unusable, and often new materials that become waste. Recognized internal barriers to reuse from the interviews involve the lack of company strategy, damaged products, and the lack of markings on used products. Douglas et al. (2019) adds other barriers to reuse, such as buildings not been designed for deconstruction, scarce workforce in deconstruction, and project planning and permitting do not encourage salvaging of materials. Lack of time in the project process and space on-site for waste sorting pose another internal barrier to the implementation of CE principles, as new processes require time to apply and waste sorting requires space to be performed well. The company is currently locked into a sustainability agenda oriented to environmentally certifying buildings, which is also recognized as an internal barrier, as these certificates rarely contain aspects regarding resource use and waste generation. Neither does Castellum measure the amount and source of all the waste which hinders the application of better methods for handling of waste, nor do they own the furniture and equipment in the offices they rent out.

External barriers to reuse are recognised as construction rules and regulation hindering reuse, the lack of market for reused materials and products, no control over the origin of materials, and no standards for measuring circularity. A lack of guidelines on recycling and taxes on virgin materials from governmental bodies is another external barrier identified. This makes the price of virgin materials often lower than the price of reused/recycled ones. As Duran et al. (2006) suggests the economic viability of reuse/recycling will likely occur when the cost of using reused/recycled materials is lower than the cost of using virgin ones. This low profitability of recycled materials causes another identified external barrier: an unbalanced supply and demand of these materials. The final external barrier derived from the empirical data is the lack of a standardized CBM within the built environment as well as funding difficulties for these because of unclear market demands for them (Guldmann and Huulgaard, 2020).

Enablers:

Raising awareness of environmental issues in the world and the potential benefits that CE could have on solving them was identified as the first external enabler. The following enabler is a strong market demand for office spaces which offers reliable financial support and economies of scale to Castellum that are crucial for the implementation of CE in the built environment (Górecki et al., 2019, Hart et al., 2019). The last external enabler identified is the cost savings potential of CE principles.

Castellum is a real estate investor with a high purchase power that owns all its properties, has a long-term vision of the company's strategy and a high shareholder/top management buy-in into circularity. All of these were recognised as enablers for implementing a CBM. Certain tools and technologies that the company uses were aslo identified as enablers to improving the resource use and waste

management: *One Click LCA*, that could be used to measure circularity, BIM and VR, as technologies for collaboration and design strategies, which according to Hart et al. (2019) represent a sectoral driver for CE in the built environment. Both the tender process to award projects and the collaborative nature of partnerships with stakeholders that is common at Castellum are recognised as potential enablers, as procurement can consider cirular criteria, and engaging in collaborative circular networks and partnering with suppliers is required to implement CE in business models (Hofmann; Lieder et al., cited in Kristensen and Remmen, 2019). Finally, Castellum is part of *Återbruk Väst* and has an internal reuse warehouse on Ringön (Gothenburg) that has the potential to strengthen the regional reuse marketplace (Douglas et al., 2019).

Challenges:

Castellum aims to be climate neutral by 2030, throughout their value chain, as 98% of their emissions come from their value chain: projects, subcontractors, and materials. This is recognised as the first challenge aligned with the efforts by the European Commission (2020) of driving the industry towards climate-neutrality. The second challenge is meeting client desires, as clients are the main driver in Castellum's decision making process. This is recognised as a challenge as they do not always match Castellum's sustainability agenda and their desire to shift towards a CBM. Adams et al. (2017b) claims that it is precisely the clients who have a pivotal role in addressing the challenges to implementing CE within the building sector. The third recognised challenge is the complexity of the supply chain. Castellum's biggest environmental impacts come from materials, as is common for the industry. This is mainly due to the generation of (CDW) and the manufacturing of building materials (López Ruiz et al., 2020). The fourth and final challenge gathered from the data collected is that Castellum does not have much control over the waste that their business processes produce. The contractors responsible for the projects take care of the waste from the sites, with ocular controls performed by Castellum, while the demolition process is often not optimized enough to accommodate reuse and recycling at the end-of-life stage. These inefficient management practices often imply larger volumes of CDW (Esa et al., 2017).

5.3 Stakeholders

The third subchapter of the analysis aims to answer the third research question:

- RQ3: What role do Castellum's various stakeholders play in the management of resources use and CDW?

A stakeholder analysis was performed to identify the key stakeholders with the following questions in mind "Who has the highest impact on resource use and waste generation?" and "How can these stakeholders be influenced in supporting the creation of a circular office?". A summary of the results is presented in Figure 5 and described in the following text:

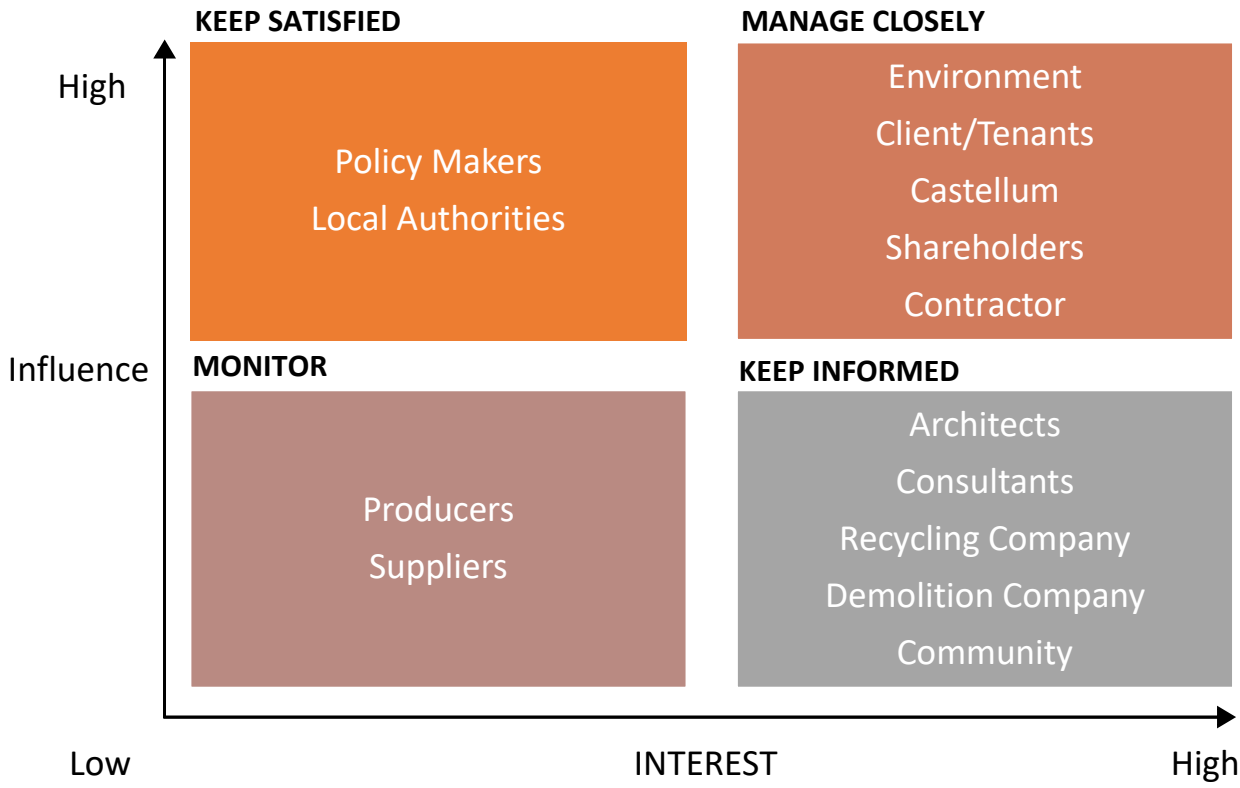

Figure 5. Influence - interest grid.

High interest and high influence

The stakeholders labelled to have both a high interest and high influence are the environment, as it is the main driver for a shift towards a CBM, clients/tenants, as Castellum is a real estate company providing service that is driven by client needs and desires, the company itself, along with the shareholders, and the contractors, due to the reason that the construction process is one of the largest waste sources and the nature of the contracts used in the project development, which give the contractor high influence over the resource use and waste generation.

The stakeholders in this category are to be managed closely, as they are recognised as crucial in transition to a CBM. A more detailed analysis on how to influence these stakeholders is presented in chapter 6.

High interest, but low influence

Architects and consultants, recycling and demolition companies, and the local and global community are labelled as having a high interest/impact, but lower influence as they rank lower on the decision-making scale but contribute significantly to the resource use and waste management. Architects and consultants are crucial in the design stages of the project, while the recycling and demolition companies are crucial in the end-of-life stage of projects and products. The community has a high interest because they interact both with Castellum and with Castellum's tenants and are affected by the company's performance. The community is considered an external stakeholder, while the rest are internal ones, as they are employed by Castellum in the project development process.

The stakeholders in this category are to be kept informed, so that they can comply with Castellum's requests and aid on the transition towards a CBM.

High influence, but low interest

Policy makers and local authorities are considered to have a high influence, as Castellum and the whole industry must comply to their rules and regulations, but a low interest since Castellum does not have a significant influence over their decision-making process.

These stakeholders are to be kept satisfied, meaning Castellum must meet their requirements and abide by their rules and regulations.

Low interest and low influence

Even though the producers of materials and products and various suppliers are often considered essential in supply chains towards a CE, they are identified as having a low interest and influence to Castellum, as they usually supply the contractor(s) performing the work in the project which adheres to Castellum´s criteria and they supply the market demands set by investors.

As Castellum aims to be climate neutral throughout its value chain, these stakeholders supply of products and material is to be monitored to comply with the criteria or standards set.

In summation, the stakeholder analysis offers an overview of the actors responsible for the resource use and waste generation. The clients are flagged to be among the most important stakeholders, as they are the end users of the office and drivers of both new build and renovations. The contractors are also seen here as crucial, because of the nature of the contracts used and the construction process, which both leave little room for improvement and they are critical stakeholders in the shift towards circularity. Architects and consultants are labelled as secondary actors here, as they were shown to be more open to innovation regarding sustainability and circularity. Since the recycling and demolition companies can most easily profit financially from better waste management, they are also viewed as secondary, despite the fact that they influence the end-of-life stage, which is the most wasteful phase of the building's life. The stakeholder analysis thus offers a strategy to aid the transition towards a CBM, as it pinpoints where more effort, time, and/or money needs to be diverted to get stakeholders onboard.

The value chain

Business can be understood as a set of relationships among groups which have a stake in the activities that make up the business (Freeman, 2010a). Castellum, as a real estate company, acts as an investor/client in the construction process, which makes most of the stakeholders listed their suppliers and gives Castellum decision making power. Castellum's clients, on the other hand, are their tenants, who carry the power of driving the company's business and decision-making processes, as client desires are the main driving force. This creates a value chain that puts the clients/tenants on the downstream, Castellum in the middle, and the suppliers (contractors, architects, demolition companies etc.) at the upstream of the value chain. To meet the client requirements, thus, Castellum puts demands on the suppliers. Which does not mean that the clients/tenants cannot be influenced in making decisions that support a CBM.

Customer segmentation

To offer more value to the clients/tenants a customer segmentation is needed to pinpoint what aspects clients value more or less. Almquist et al. (2016) suggests that there are many ways to succeed by delivering various kinds of value. The company does not perform any detailed customer segmentation beyond the division by industry and income received from rent, which makes it difficult to pinpoint which clients would be more accepting to CBMI. Based on the data collected the clients more accepting to this are usually smaller companies more open to variations, those located in the central business areas of bigger cities, and some bigger companies that have high sustainability requirements. Small leases (under 0.5 MSEK) make up 63,6 % of the portfolio, medium ones (0.5-3.0 MSEK) 27,6 % and big clients 8,8 %. The small leases make up 11% of the portfolio's value, medium ones 35%, and big ones 51%, with an additional 3% going towards residential and parking spaces (Castellum, 2019). A better understanding of what drives client desires and what they value would be helpful in offering a better value proposition. Targeting a more circular offer to clients mentioned above, the ones that value sustainability more, is viewed here as the basis to creating a CBM.

Stakeholders along the value chain

As the construction sector is characterised often as conservative, uncollaborative, and adversarial (Hart et al., 2019) a partnership approach to the relationships among stakeholders is needed. The architects/designer are the ones recognised as most willing among the main stakeholders to cooperate in matters of circularity. As the design stage is often seen as the most important one for the management of CDW these partnerships need to be built and maintained to aid the transition to a CBM. The contractors were seen by the interviewees as less cooperative and more inclined to a "business-as-usual" way of doing things, so stronger demands on them are needed to have them follow along on this path towards circularity.

Demolition companies are responsible for the waste from the demolition process, and this process is one of the most wasteful ones, so further attention is needed here to make it more efficient. The recycling companies take care of the waste from construction sites and are thus also important for the end-of-life stage of the products/materials. Demolition companies rarely go beyond what is required by law from them, and Castellum does not tend to put specific demands on them beyond the legal requirements. Similarly, the recycling companies focus their efforts into profitable materials while also complying with the laws and regulations. When it comes to producers and suppliers, they are key for the supply of new products, and are influenced by demands on the market.

6. Recommendations

The following chapter gives recommendations based on the analysis of the empirical data and the literature reviewed, while answering the fourth research question, and fulfilling the aim of this paper.

6.1 Recommendations of CE principles to the project level

The fourth subchapter of the analysis aims to answer the fourth research question:

- RQ4: How can the principles of CE improve Castellum's and Castellum's stakeholders' performance on the management of resources and CDW?

Based on the analysis of the status of the company, challenges, barriers, and enablers, and the stakeholder analysis, certain principles of CE were chosen to promote the company's transition towards a CBM that best fits the company. These proposed solutions are divided by stakeholders involved and if they fall into large renovations and new construction, as they involve a development and tender phase or small renovations, as well as recommendations on a strategy level.

		CIRCULAR ECONOMY PRINCIPLES	STAKEHOLDERS
SMALL RENOVATIONS			
		Circular procurement	Contractor, Supplier
		Selective demolition/deconstruction	Contractor, Demolition companies
LARGE RENOVATION AND NEW CONSTRUCTION	PRE-CONSTRUCTION	*Circular design*	Architects, Consultants
		Design for waste prevention	Architects, Consultants
		Design for longevity	Architects, Consultants
		Design for disassembly	Architects, Consultants, Demolition companies
		CDW management plans	Architects, Consultants
		BIM material logs	Architects, Consultants
	CONSTRUCTION		
		Circular procurement	Contractor, Suppliers
		Site waste management plans (SWMP)	Contractor
	END-OF-LIFE		
		Pre-demolition audits	Contractor, Waste auditor
		Selective demolition/deconstruction	Contractor, Demolition companies
STRATEGY LEVEL		*Customer segmentation*	Clients/Tenants
		Fully furnished offices (*Servitization*)	Clients/Tenants, Architects, Suppliers
		Adopt stewardship role	Castellum and the supply chain
		Circular pilot projects	Castellum and the supply chain
		Internal sustainability goals for CDW	Castellum
		Internal measurements for circularity	Castellum
		Återbruk Väst	Castellum and the supply chain

Table 4. Circular business model innovation (CBMI).

To achieve their goal of climate neutrality changes are needed in the company's business model and along its complex supply chain. These recommendations are summarized in table 3 and described in the following text. As their biggest impacts come from materials, mainly due to the manufacturing of building materials and generation of CDW, CE is viewed here as the optimal tool to overcome this challenge**.** Principles of CE need to be introduced into all stages of the project processes and translated into company strategy. Based on the data acquired and analysed, both from the empirical and theoretical data, a set of CE principles were chosen to facilitate the shift towards CE. These principles, if applied, would result in innovation in the company's business model, labelled as CBMI. In the following text these are described and analysed, divided by project level and strategy level. The stakeholders relevant for each point are highlighted and ways on how to influence them are given.

CE needs new business models to translate circular strategies into competitive advantage, company resilience, and successful revenue models (Peck et al., 2019). In order to get there, Castellum needs to change the way they operate on a project level and translate this into company strategy. Circular value creation is at the heart of this shift, and it includes strategies along the value chain. This needs to be followed by changes on the industry and legislative level to make it common practice, but this falls beyond the scope of this research paper, as it examines only one real estate company who, as the literature suggests, are a fundamental driver for a transition to a circular built environment (Acharya et al., 2020). Based on the analysis of the status of the current business model and practices at Castellum, the recognised challenges, barriers, and enablers to implementing a CBM, and the stakeholder analysis, strategies are suggested in this subchapter on achieving CBMI that would reduce resource use and waste generation.

Customer segmentation

As Castellum is seen here as a service provider, where customers' needs and requirements are a crucial driver for the business, these need to be addressed first. For the time being, the company does not perform a detailed customer segmentation, which is needed to best pinpoint which customers would be more willing to accept circular solutions, even if these might cost more. As part of a short-term strategy, customer segmentation is essential, while on a long-term it would not be needed any more, as a CBM would be the only offer available. This recommendation can apply for all types of projects such as small and large renovations and new construction.

As small renovations differ from large ones and new construction, both in scope and in the tender/procurement process, the recommended CE principles were divided accordingly and are described in the following text:

- *Small renovations*

Smaller renovations are characterized by two main features: the scope is small, and it involves relatively simple works, like repainting, the changing of carpets, partitions and similar, and they do not involve a tender process. Castellum usually hires one of their frequent suppliers (or a new one) and draws up a contract for the work.

The biggest issues recognised here is that Castellum takes little to no responsibility of the materials used. They claim this is a result of the lack of market for circular products and lack of time and planning in the project process.

The CE principles chosen for smaller renovations are C*ircular Procurement* and *Selective Demolition* (if demolition is involved at all). *Circular Procurement* would involve procuring products with a high content of recycled material, circular products, meaning better quality products, or new innovative products, or used products. The products information could be supported and documented by BIM material logs. The selective demolition, if needed, would be used to aid better management of waste, thus enabling reuse (with repair, refurbishment, and remanufacturing), and recycling, if reuse is not an option. Landfill is to be avoided at all cost, while energy recovery is acceptable only for materials with high caloric potential (like plastics and wood).

As Castellum has identified that some materials and products in their offices are in good shape and conditions during a renovation project, they have put in efforts in salvaging them. The company has warehouse where they store all the materials and products that can be internally reused. As described in the empirical data it was the project managers who developed this initiative for their own portfolio, and it is now intended to be a sharing platform for all the projects.

- *Large renovation and new construction*

Large renovations and new construction are grouped together as they both involve a more complex planning stage and go through a tender process. The recommendations given here are thus divided by project stages.

Pre-construction

In the pre-construction stage of the project process the design is a crucial element to introducing circular strategies. As Castellum does not do the design themselves, but hire architects and consultants, these are the stakeholders responsible to implement these strategies. The possible CE principles shown to give the best results in this stage are *circular design*: *design for waste prevention, design for longevity, design for disassembly or deconstruction, use of prefabricated elements,* and *CDW management plans.* As shown in the empirical data, architects and consultants are the stakeholders most willing to implement CE principles in their work, thus a collaborative partnerships is suggested here, as it has the potential to create feedback loops that yield the best results, especially in the short-term when these new strategies are still in the testing phase. Applying *circular design* strategies has been shown to extend the design phase and stretch out its budget, but early involvement of designers has the potential to reduce these negative impacts on the project.

A *circular design* that allows for the building in layers can facilitate that "each element is more easily repaired, replaced, moved, or adapted, without affecting the whole building" (Acharya et al., 2020). This can increase the building longevity and contribute thus to its circularity. *Design for disassembly* is part of a long-term strategy, as its benefits are expected to be seen at the end-of-life of buildings when they are to be disassembled. Since Castellum operates on a long-term strategy and builds to own, this is considered to support that vision, as it will result in salvaged materials at the end of the buildings life. Some of the principles of *design for disassembly "*are feasible in today's practices, like modularization and prefabrication" (Cruz Rios and Grau, 2019), while more complicated ones require additional efforts on the side of the designers. Collaborative partnerships with them are thus seen as the way to go, as the motivation is the environmental value gain and innovation, not financial. This would imply earlier engagement in the project process with the designers, contractors, and demolition companies.

To reduce the waste generated in the construction stage *CDW management plans* can be requested from the designers. This could be part of the collaborative partnerships established, or one of the criteria in the procurement process of the design services. As Castellum already requests BIM models from the designer for all the designs they procure, these are an opportunity to contain detailed material logs that would enable better deconstruction at the end-of-life stage which would enable reuse and recycling of materials, thus offering also economic benefits, along with environmental ones. Crucial to implementing these strategies are the stakeholders: designers, architects, consultants.

Construction

When procuring for construction services, for large renovations and new buildings, Castellum employs tenders where they establish the project criteria. Employing incentives and penalties in the past has not always worked well, so they establish these criteria now as a demand. Adding circularity criteria on materials or through *Circular Procurement* has the potential of reducing Castellum´s environmental impact, as materials represents the main generator of CDW in the built environment (López Ruiz et al., 2020). These criteria can include various CE principles aimed at reducing resource use and waste generation, such as using reused/recycled materials, building products with low material content and low embodied energy (Migliore et al., 2020), better on-site waste sorting, and SWMP among others.

The adoption of SWMP has been identified by Esa et al. (2017) as the main strategy for improving the CDW management operations by reducing waste and increasing the recovery rates of materials. By including this criterion in the procurement stage, not only Castellum but all the stakeholders within the value chain would directly benefit from the retained value of materials and recyclability rates.

As Castellum has a high shareholder/top management buy-in into circularity and high purchase power, they have the capacity of demanding these criteria in the procurement process which is fundamental for a transition to a CE in the built environment (Hart et al., 2019), even if these criteria increase the project cost.

End-of-life

Pre-demolition audits (or waste management audits) are a requirement for carrying out large renovation or demolition projects, they help identify the sources and amount of CDW, such as hazardous materials among others, and specify the dismantling, deconstruction, or demolition practices. The waste audits are carried out by a qualified expert (waste auditor or environmental consultant) who is suggested to be employed by the client or “waste owner” as described by the EC. Mapping the project process at Castellum through the data collected from the interviews, it is the main contractor who normally employs the waste auditor acting as *totalentreprenad.*

The CDW management practices in Castellum´s supply chain is not optimized enough. The waste audits performed in Castellum´s supply chain by the contractor focus solely on the minimum legal requirements which refer to the waste source and quantity with emphasis on hazardous waste, Castellum could set the demand of conducting more thorough waste audits. Currently, these were not recognized by any of the interviewees as a priority to the company. Performing waste audits earlier in the project and incorporating them in the tender as well as conducting the recommended waste audits by the EC, which include information about the waste logistics and recovery processes among others, can reduce the environmental impact, increase recycling rates and retain the value of materials.

Combining these more detailed waste audits with selective demolition/deconstruction is another chosen CE strategy that could increase reuse and recycling rates, preserve the value of materials and products at the end-of-life stage, and reduce the overall impact, which is especially important for this stage of a buildings life, as it is one of the most wasteful ones. Selective demolition/deconstruction can be considered both a short- and a long-term strategy, as in the long-term it is expected to yield even higher returns on value gained/preserved, when the benefits of circular designs, mostly *design for disassembly*, start paying off.

6.2 Recommendations of CE principles in the Use stage

The fact that Castellum does not furnish the offices they rent, is considered a barrier here to implementing circularity as it leaves the control over these resources to third parties or the client itself. This barrier can be turned into an opportunity by expanding the offering of the company while simultaneously contributing to the circular performance. This servitization combined with *adaptive remanufacturing* can contribute to value preservation and play a role for sustainable and long-lived products (the furnishing of the office). *Adaptive remanufacturing* is also suggested here to be used in office renovations, for products and materials that can accommodate it. This would indicate also finding suppliers in the supply chain that offer these services along with take-back schemes with remanufacturing, thus extending Castellum's circular value chain.

Renting fully furnished offices, furnished with circular products and materials, is considered a potential long-term strategy that could add new revenue streams, while contributing to the circularity of the business. Castellum has already cooperated with companies that remanufacture furniture and has been involved in a pilot project with a large Swedish furniture manufacturer to equip their offices with leased circular furniture. Expanding on this and incorporating it into their offer would drive another aspect of the CBM. Combined with customer segmentation to pinpoint which tenants would be willing to rent such an office is the chosen strategy here.

6.3 Circular Business Model Innovation / Strategy

Applying the principles of CE to the built environment can create a sector that is resilient to volatile prices of raw materials, that maintains essential natural ecosystem services, and that creates urban areas that are more liveable, productive, and convenient (Acharya et al., 2020).

The principles chosen for the pre-construction stage of the project process are meant to design out waste and reduce carbon emissions, the ones described for the construction phase to reduce the waste generated and increase the recycling rates, and the end-of-life ones to preserve value from materials. The suggested extended offering of renting fully furnished offices is meant to keep products and materials that comply with the circularity criteria in use for longer, thus extending their life cycle.

Efforts need to be made along the supply chain to secure support for these changes in the company's business model, so that it can embed itself in a circular value network. As Castellum is a real estate investor with high purchase power and influence, they are in a unique position to drive this shift towards circularity forward for the whole industry. The first step in this process would be pilot projects where the principles describes are used, targeted towards customers/tenants that value solutions like these and done in collaborative partnerships with relevant stakeholders.

To adopt circular practices along the supply chain, Castellum should adopt a stewardship role, by procuring *circular design*, embedding circular criteria in the tender process, and engaging in

collaborative circular networks with suppliers, manufactures, and customers. The company could introduce internal sustainability goals for waste generation and improved efforts for managing and measuring waste on site which is not the common practice now. Further efforts could be made to strengthen the companies reuse processes, while also influencing the overall reuse market. The *Återbruk Väst* initiative is seen as a good opportunity as it is already a part of the company's agenda, but still in its infancy, so it requires further development. Same goes for the measurement of circularity, there is no industry consensus on them, which makes it harder for companies to implement circular solutions as they cannot measure them. Castellums attempts with *One Click LCA* are considered a positive step forward, as it contributes to the development of circularity metrics.

By reconfiguring the existing business model to include the chosen circular components a CBMI would be achieved, one that is driven by service and performance that would retain the value of materials longer. Since there is no standardized CBMs currently in the industry this could also be a pilot CBM for the industry. Measurement of the success of failure of these implemented principles would offer a feedback loop that enables the best choices to be adopted, while also continually expanding the circular supply network, by looking for new alternative materials and products. Despite the barriers in place, Castellum's position on the market makes them a possible leader in the industry on the path towards a circular built environment.

7. Discussion and conclusion

The discussion and conclusion chapter are intended to summarize the key findings, answer the research questions, discuss the implications and limitations of the findings, and offer the authors' interpretation of them.

7.1 Turning challenges and barriers into opportunities

The purpose of this Thesis was to contribute to the general knowledge base on the topic of CDW and improving the case study's company management of it. This was done by observing the status of CDW management at Castellum, defining the challenges, barriers, and opportunities in improving it, analysing the stakeholders involved and finally offering recommendations to the company based on the principles of Circular economy.

Despite a significant awareness on matters of resource use, waste generation and CE in the company, the results indicate that that Castellum does not perform particularly well on these matters. Certain initiatives are recognised, along with efforts to increase reuse, but beyond that, the company's processes are in line with the industry practices, meaning large quantities of waste are produced and vast quantities of resources and materials are consumed to drive the business. The analysis confirms that this is due to still existing considerable barriers and challenges for implementing CE in the company's business processes, and these need to be overcome to implement a more CBM. They revolve around both internal and external barriers. External ones include regulatory and market barriers among others, while internal ones revolve mostly around the nature of the project process, the complexity of the supply chain, lack of strategy on resource use and waste, and client desires.

It is the opinion of the authors that these challenges and barriers can be overcome, some of them even turned into opportunities for value adding. By implementing principles of CE in the company's business model value can be added along the supply chain and society. CE has the potential to increase social value by creating jobs at a local level, reducing resource use and waste generation, which can be a cost reduction for the company also, while providing both competitive advantage for the company and market resilience against resource deficiency. To implement circularity in the whole industry efforts are needed from all actors involved, regulatory bodies, the market side, clients, contractors, and designers among them. The industry is still a long way from circularity, but companies like Castellum can, and should, be at the forefront of this movement. Their combination of purchase power, top management buy-in and position in the Scandinavian region is why the authors of this paper perceive so.

7.2 The implications and limitations of the study

The results of this study are in line with the previous research analysed. They show that Castellum performs in a similar fashion to the rest of the industry and reveal how big an influence they have on their stakeholders and the industry, which corresponds to the literature claiming real estate companies are the main drivers of innovation in the industry. The recognised challenges, barriers, and opportunities to implementing CBMI also coincide to a big degree with those listed in the literature available, showing how the industry faces similar obstacles on the way to circularity around the globe. These results should be considered when re-evaluating how the company creates value for its stakeholders, as it considers the environmental impacts of the industry.

Most of the CE literature is oriented to production and manufacturing. Also, the available studies referring to the construction industry focus mostly on the contractor side, while few refer to the real estate investor/owner, which this study demonstrates as being of high importance and influence for the industry as a driver of change. The results of this study focus mostly on Castellums perspective of the issues at hand, which the authors acknowledge as a limitation of the study. No empirical data was acquired from contractors or designers/architects. This was due to unforeseen obstacle in time and access, and the authors recognise that they could have influenced the results of the study, as these stakeholders are of high importance to achieving the end goal of CBMI. Due to this lack of data, the results cannot confirm without a doubt that some of these stakeholders would be willing to easily adapt to and support Castellum's CBM. Despite these limitations the authors still feel the results are valid, as the main audience and the main contribution of this study is to the case study company – Castellum, which has high influence on its stakeholders.

7.3 The circular office guidelines

To answer the fourth research question, and fulfil the aim of this study, guidelines are suggested for the company on creating a "*Circular Office*" offering. These include CE principles to be applied in the project process, be it in small office renovations or large renovations and the building of new offices, along with further servitization of the business. By translating these project processes to the business model level CBMI is to be achieved. In the initial stages of the implementation of these CE principles a certain degree of flexibility is needed. The authors recognise that innovation most often happens incrementally through collaboration and requires time and effort to become "business-as-usual" for a company.

The circular principles recommended are categorized on two different levels: project and strategy. The *Project Level* encompasses *pre-construction, construction, and end-of-life* of the project. It focuses on how Castellum as a client with a high purchase power can influence different stakeholders along the value chain. As the stakeholder analysis suggests, stakeholders are most likely to be influenced in different ways. Collaborative partnership with stakeholders that have low influence, but high interest is encouraged. These include Architects, Consultants, Recycling and Demolition companies. While stakeholders with both high influence and interest are suggested to be managed closely and influenced through a set of circularity targets/goals within *circular procurement* and higher demands for circularity.

The *Strategy Level* on the other hand, focuses on the business model and the usage stage resulting into a CBMI for the company. Despite the lack of standardized CBMs available Castellum is believed to have the ability of adopting a stewardship role and of investing more efforts in developing internal circularity and CDW goals, as well as continue supporting initiatives such as *Återbruk Väst* towards a circular built environment. By monitoring the implementation of principles applied, a feedback loop of lessons learned would be created which would optimize the innovation of the business model.

Further research is needed to establish the level of acceptance of various stakeholders to enable the implementation of CE in real estate companies' business models, and research on pilot projects for these initiatives. Since there is a lack of CBMs currently in the industry Castellum could make pilot projects. Measurement of the success or failure of these implemented principles would offer a feedback loop that enables the best choices to be adopted, while continually expanding the circular supply network. Despite the barriers in place, Castellum's position on the market makes them a possible leader in the industry on the path towards a circular built environment.

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Appendix

Appendix 1. Summary of reviewed product-level circularity metrics (Linder et al., 2017).

Metric	*Construct validity*	*Reliability*	*Transparency*	*Generality*	*Aggregation principles*
Material Circularity Indicator (Ellen MacArthur Foundation and Granta 2015)	Medium Measures use of virgin material and resultant waste to landfill or energy recovery. Loop tightness not considered (though mentioned as potential future development).	Low Many data inputs required that might be uncertain or depend on several factors, such as ex ante assumptions regarding the destination of a product after use and the efficiency of recycling processes.	Low Required data (includes bill of materials of all components) normally considered confidential. Difficult to verify by a third party.	High Indicator can be applied to wide range of products.	Medium Circularity represented by a single value ranging between 0 and 1. Acknowledged difficulty weighing different types of cycles. Not applicable to every product, only for reference products that represent a group of similar products.
Eco-efficient Value Ratio (Scheepens et al. 2016)	Low Measures environmental impacts per euro spent, not necessarily focusing on closed material loops, but implicitly taking into account circular economy effects as sharing, reusing, and renewable energy.	Low Requires many data inputs for robust outputs. Environmental impacts during usage included, although uncertain: depends on the condition of use.	Medium Verifying eco-cost of a product might be difficult because of confidentiality. Content of product may be difficult to trace in upstream supply chain.	High Ratio can be applied to wide range of products.	High One easily understood value per product for specific use (functional unit).
Circular economy index (Di Maio and Rem 2015)	Low Measures recycling rates, excluding all other circular economy effects and loops.	High Detailed data on all products and components entering the recycling facility are required—information not commonly available. Index is computed per recycler, outputs can differ significantly depending on product assortment of recycler.	High If index is based on standards (e.g., material passports).	Low Only applicable to recyclers with same assortment.	N/A

(Continued)

Metric	*Construct validity*	*Reliability*	*Transparency*	*Generality*	*Aggregation principles*
REPRO (e.g., Gehin et al. 2008)	Low Reuse and recycling are excluded	Low Dependent on ex ante assumptions regarding potential future remanufacturing.	Medium Requires detailed information about product parts, interfaces and processes.	Medium Applicable to many industries, but only remanufacturing loops.	Low Does not enable aggregation of different types of (non-reman.) cycles into a single value.
Material reutilization part - Cradle-to-cradle (C2C 2014)	Medium Loop tightness not integrated (though energy recovery considered special case).	Unknown We have not been able to find enough detail to properly assess this. Includes ex ante assumptions regarding recirculation.	Low Required data (include bill of materials of all components) normally considered confidential. Difficult to verify by a third party.	High Can be applied to wide range of products.	Low Does not allow for a fine-grained value summarizing degree of circularity (five ranks). No theoretical justification for weights for different combinations of cycles and materials

Note: REPRO = Remanufacturing Product Profiles; N/A = not applicable.

Appendix 2. Circular Business Models (Fehrer and Wieland, 2020).

Circular business models.

CBM Value Creation Logic (Zott & Amit, 2008)	**Efficient material-technical loops** (Bocken et al., 2016; Esposito et al., 2018; Geissdoerfer, Morioka, de Carvalho, & Evans, 2018; Hopkinson, Zils, Hawkins, & Roper, 2018; Khan et al., 2018; Leising et al., 2018)	**Effective product-service loops** (Hobson et al., 2018; Pialot et al., 2017; Tukker, 2015; Yang, Smart, Kumar, Jolly, & Evans, 2018)	**Social-collaborative loops** (Lacy & Rutqvist, 2015; Todeschini et al., 2017; Wells & Nieuwenhuis, 2018)	**Symbiotic ecosystems** (Bocken et al., 2014; Gallo et al., 2018; Stal & Corvellec, 2018)
Content: *changing and creating (new) activities*	Maximizing material and energy efficiency: ■ Developing and building for durability ■ Repairing, refilling, and refurbishing ■ Recycling and collecting ■ Upgrading	Deliver functionality rather than ownership: ■ Paying for use ■ Leasing ■ Renting ■ Maintaining ■ Servitisation	Proactively engage all stakeholders: ■ Sharing ■ Diffusion of sustainable practices ■ Slowing down consumption	Driving systemic change: ■ Re-purposing the role of business for the society and environment ■ Restoring and reincarnating ■ Scale-up solutions
Structure: *linking activities, resources, and actors in new ways*	Circular supply chains, vertical (forward and backward) integration	Service solutions, vertical (forward) integration	Collaborative consumption platforms, network integration	Open associative and collaborative networks, network integration
Governance: *ways of governing/ managing the activity system*	Supply chain management, firm-centered contractual models	Service management, firm-centered with contractual models	Platform orchestration, decentralized with collective contractual models	Collective entrepreneurship, multi-organizational governance, decentralized with collective authority

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