Master's degree thesis

LOG953 Sustainable Energy Logistics

Designing for the circular economy: A multiple case study of the Norwegian building construction industry

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Preface

I would like to thank my supervisor, Nina Pereira Kvadsheim, for all her input towards this final product. We have had several discussions where she came with really good feedback and I really appreciate that. She has been kind and patient with me all the way and was always easily accessible. So, thank you Nina!

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Mats van Teeffelen

Abstract

Purpose – This study aims to explore circular economy (CE) principles in the building construction industry. Focus is put on CE design methods, how to implement these, its barriers towards implementation, and how these barriers can be overcome.

Approach – In order to perform research on the subject of CE design principles in the building construction industry, a literature review and a multiple case study has been performed. It is a qualitative study where data was collected through semi-structured interviews. Five companies from the construction industry have been interviewed. The goal of the interviews was to gain insight into the current CE practices, its barriers and drivers.

Findings – From the interviews, it is shown that design for deconstruction, flexibility and standardization are considered the most important CE design practices in this industry. A currently lacking system of standardization and CE material market are needed to implement these design practices. Barriers mentioned interrupting this implementation are lack of CE knowledge, lack of incentive to change for suppliers, several material procurement barriers, high initial costs and as most influential, power of building owner. In order to overcome these barriers, government support was proposed as a solution in order to gain CE knowledge in pilot projects. Closer collaboration with suppliers is needed to improve CE material procurement. Stricter CE regulations are needed to press building owners into becoming more CE aware.

Discussion- When comparing the literature with the findings from the interviews, several other design methods were mentioned focusing on, among others, energy efficiency and waste. In the literature, more focus was also put on contracting in order to align economic interests. In order to let the building owner focus on CE practices, the literature proposes to create economic incentive.

Conclusion – One of the practical implications is the implementation of regulations in order to shift focus to become more CE oriented. One of the limitations of this study is the small number of interviews.

List of Acronyms

CE –	Circular Economy
BREEAM –	Building Research Establishment Environmental Assessment Method
BREEAM-NOR –	Building Research Establishment Environmental Assessment Method Norge
DfD –	Design for deconstruction
NS –	Norwegian Standard
6S –	6S Shearing Layers
ECI –	Environmental Cost indicator
PaaS –	Products as a Service
BIM –	Building Information Modeling
C1, C2… C5 –	Company 1,2…5
AI –	Artificial intelligence
LCC –	Life Cycle Cost
ROI –	Return on Investment

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1.0 Introduction

1.1 Chapter introduction

This chapter gives an introduction of the thesis. It shows a relevant background, focuses on the research problem and from this, relevant research questions follow. The research questions form the base of the focus of the literature review and the interviews. The background is divided into parts focusing on the growth of society and its need for materials, a short explanation of CE and a definition of the construction industry. Further, a research gap is presented, explaining the focus of this research.

1.2 Background

The earth's population is expected to be approximately 9.7 billion people in 2050. All these people will need a place to live, work, exercise and hang out. All this calls for an increase in infrastructure and buildings worldwide. For these buildings to be constructed an increase in material use is needed. It is expected that worldwide material consumption will increase towards 90 billion tons in 2050. This is double the number of materials that was used in 2015. The global construction industry consumes the most resources worldwide and is also responsible for a third of the total world's waste. The expected waste generation by the construction industry will be 569 million tons in 2025. Although construction waste has high recycling potential, only 40% of the waste is actually recycled. The biggest part of the waste generated ends up at landfills. The construction industry also produces roughly 40% of the world's CO_2 emissions (Guerra et al., 2021; Miller, 2021).

As all materials on earth are finite, depletion of materials will become an end result. If society wants to keep growing at the current rate it needs to change its habits when it comes down to material use. Otherwise, material depletion will become a standard. A possible method for creating a more sustainable construction industry is by implementing a circular business model, also known as a circular economy (CE).

CE is a model of producing and consuming, which is focused on reusing materials and products for as long as possible. For example, trough repairing, sharing and recycling. This is different from a linear economy where products are disposed of after the use of a single lifetime or less (European Parliament, 2022).

Fritz Benachio et al (2020) show that research on CE within the construction industry has increased in recent years. The current mode of production in the construction industry is based on a 'take, make and dispose' model, in which, materials are extracted (take), then turned into usable products (make) and after the products are not usable anymore, they are thrown away (dispose). Companies gain profit by producing and selling as much as possible, a product with a short lifetime is thus more profitable (Ellen Macarthur Foundation, 2015).

European Environment Agency (2022) shows that CE has a positive impact on the reduction of greenhouse gases where only the reusing of materials can generate savings of 100 million tons of CO2 equivalent. Besides, economic improvements are also achievable. For example, Büchele & Schober (2021) state that a global market worth €600 billion will arise by 2025, with a yearly growth rate of 12%. Although all of these profits are available, the construction industry has been struggling to transition towards a CE. This is due to lack of digitization, complex products and its unwillingness to change (Wuni, 2022).

Pheng & Hou (2019, p. 21) provide a definition which is broad and considers the construction industry as a process from raw materials all the way to the final result.

> *"Construction is referred to as an economic activity that involves the entire construction process from producing raw and manufactured building materials and components and providing professional services such as design and project management, to executing the physical work on site."*

The construction industry is often looked upon as an indicator for how well developed a country is both economically and technically. The construction industry is also considered a good indicator for whether economic growth or downfall is the next trend (Pacheco-Torgal et al., 2020).

The construction industry can be divided into three main sectors: building construction, infrastructure construction and industrial construction. Infrastructure construction focuses mostly on transport networks like rail and highways, while industrial construction focuses on things like mining and power generation. This research focuses on building construction. Building construction focuses on adding buildings which can be used for living or other inside activities to the landmass (TechnoFunc, 2020). Roughly 30% of the European CO2 footprint is produced by buildings in addition to 40% of the energy use. The building sector can be divided into residential and non-residential, for this research both will be considered (de Graaf, 2022) . In the section below, the problem with the implementation of CE practices in the building construction industry will be further specified.

1.3 Research problem

The environmental impact the building industry creates is significant, however signs of change in the industry are minimal. CE provides a practical method which can be used in order to create a sustainable way of doing business along the whole value chain. Research has been increased a lot over the years, but practical implications are missing (Fritz Benachio et al., 2020).

CE practices in the building industry are still in the early-adopter phase. Companies who have created a circular business model are often start-ups less than 10 years old and with fewer than 50 employees. Larger companies are looking at the concept of CE, but merely as a way of risk aversion, not as a main focus. Meaning that companies might consider some small CE implementations here and there but will not base their business model on CE. (Guerra et al. 2021).

Due to the knowledge in the literature but lack of practical implementation a gap has been formed. Barriers mentioned in the literature as a cause of this gap are among others unwillingness to change, lack of CE knowledge, lack of support from top management, lack of economic incentive and lack of market structure for second-hand materials (Wuni, 2022). These barriers are part of the building construction industry and its fragmented nature, resistant to change. In order to overcome barriers a complete change is needed in the building industry. This research focuses on how this change can be made.

Therefore, focus is put on the design phase. Strategic project decisions are made in this phase and have a huge impact on the total sustainability impact of a building project (de Graaf, 2022). This research focuses on what CE practices can be implemented in the design phase of a building project and how. Besides this focus is put on the barriers which keep these practices from being implemented and how they can be overcome.

Hence, this research looks into the obstacles and possibilities of transforming towards a CE within the building construction industry, and how CE practices can be implemented in different parts of the supply chain. The logistical problems at hand cover the re-design of the supply chain in all lifecycle stages of the building construction industry. This research is relevant for both the building construction industry itself as well as society as a whole due to the possible economic, ecological and social benefits which can be achieved. Based on the above-mentioned research problem, the following research questions are formulated.

1.4 Research Questions

RQ1: What CE practices can be implemented in the design phase of the construction of buildings?

Bocken et al. (2016) mention ways of slowing and closing the loop. These are concepts of thought but not straightforward implementable practices. de Graaf (2022) mentions several design methods for architects on how to design a circular building. However, these methods do not consider all parts of the lifecycle stages. For example, a method such as specify reclaimed materials, focuses on reusing materials in the procurement phase. However, it does not focus on energy efficiency. Adams et al. (2017) present methods which can be implemented during other parts of the lifecycle stages in order to create a circular building project. To answer this question research, literature from different authors is combined in order to get an overview of currently available CE practices in the design phase. This is then compared to the results of the case study in order to see how much Norwegian construction companies know about CE practices in the design phase.

RQ2: How can CE practices be implemented in the design phase of the construction of buildings?

Following the extant literature, there is a gap between the literature and the practical implementation of CE practices (Wuni, 2022). In addressing this research question, the study focuses on how the CE practices from the first research question can be successfully implemented. Here, the focus is both on internal factors like CE knowledge and willingness to change and external factors such as government support and market trends. The question is answered based on knowledge gained from literature as well as information gathered from the case studies. The case studies show what the interviewees think is necessary to implement CE practices.

RQ3: Which obstacles might interfere with the implementation of CE practices in the design phase of buildings?

The previous research question focuses on the optimal way of implementing CE practices in the design phase. When trying to optimize such an implementation, new barriers will form. In question 3, an overview is created of all barriers which were found when trying to implement these CE practices. This information is gathered from the literature review and the case studies. The case studies show more eminent which barriers are a problem in the building construction industry.

RQ4: How can the obstacles, which interfere with the implementation of CE practices in the design phase of buildings, be overcome?

In order to successfully implement CE practices and to partly address the gap between literature and practice, the implementation barriers need to be overcome. To answer this question, all knowledge and experiences gained from the literature review and case studies is combined in order to get insights into how to overcome the barriers of implementing CE practices in the design phase of the building construction industry.

1.5 Thesis structure

This research project is divided into six relevant parts. The first chapter is the introduction, which focuses on the background of this research, explains why it is relevant and its research questions. Chapter 2 presents the literature review, where information is gathered from different types of sources such as research performed by scholars and reports presented by companies and organizations. The literature review explains CE as a concept, shows an overview of the current state of the building construction industry and goes in depth on CE practices in all lifecycle stages of a building construction project. Chapter 3 explains the methodology employed by the study in addressing the research questions. Chapter 4 presents the findings, in which an overview of the data collected through the case studies and its analysis is given. Chapter 5 discusses the findings, while. chapter 6 presents the final remarks consisting of a summary, implications and limitations of the research.

2.0 Literature review

2.1 Chapter introduction

In this chapter, relevant literature and frameworks, in order to solve the research questions are presented. First, the concept of circular economy is covered, then an overview of CE practices in the building construction industry is provided. At last, the CE practices for the construction lifecycle stages are described.

2.2 The concept of Circular Economy

In this sub-chapter a closer look is provided on the concept of CE. A history of CE is provided, along with a clear definition. CE strategies are explained and information is provided on CE practices in the design phase.

2.2.1 Origin of CE

CE started to take off in the beginning of the second century. Around the time of the second world ware different CE initiatives were becoming more popular around the globe. Supermarkets both in Europe and America started to create shopping baskets and carts in order to reuse these. In Japan, a country which was having limited resources at the time of the war, was forced to make better use of their resources and thus became more circular. Around the 1970's two industrial designers proposed production based of recycled materials, with the producer also being responsible for the waste produced in the production chain (Arrive, 2023).

Around the same time, governments became more aware of sustainability. In 1975, the first Waste Framework Directive was created by the European Union. The goal of this framework was to create a European circular economy by 2020. In 1982, Dr. Walter Stahel, wrote a paper where he came up with the term "closed loop economy". Due to this paper, he is considered the "father of the circular economy". In 1990, the Swedish government came with a law which made producers of electronics responsible for their waste. In 1994, the cradle-to-cradle model was introduced by a Dutch chemic, named Cees van der Leest (Arrive, 2023).

From this point on, several companies and institutes have come up with CE guidelines and projects. Examples of this are recycling guidelines for electronic manufacturers in America, T-shirts for single use and the founding of the Ellen MacArthur foundation. All these initiatives helped with the development of CE. As CE is such a broad subject a clear definition is important. This will be further discussed in the next section (Arrive, 2023).

2.2.2 Definition of CE

In the research community, increased attention has been provided towards the concept of CE. However, a clear definition is not yet available. When referring to CE, a definition in the following line is often meant; a system which is designed to reuse and recycle materials to ensure a longer lifetime, and decrease waste (Kirchherr et al., 2017). Kirchherr et al. (2017, p. 9) looked at 114 different definitions of CE provided by the literature in order to find out what it really is defined as. Their starting definition is as follows:

"an economic system that replaces the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes".

Kirchherr et al. (2017) also stated that their analysis shows that CE can mean a lot of different things to different people. Therefore, a broader definition is needed. Nobre & Tavares (2021) state that CE is active on micro, meso and macro level in order to create long-term ecological, economic and social improvement for both current and future generations. Nobre & Tavares (2021, p. 10) have a different definition which states that;

"CE is an economic system that targets zero waste and pollution throughout materials lifecycles, from environment extraction to industrial transformation, and to final consumers, applying to all involved ecosystems. Upon its lifetime end, materials return to either an industrial process or, in case of a treated organic residual, safely back to the environment as in a natural regenerating cycle. It operates creating value at the

macro, meso and micro levels and exploits to the fullest the sustainability nested concept. Used energy sources are clean and renewable. Resources use and consumption are efficient. Government agencies and responsible consumers play an active role ensuring correct system long-term operation."

This definition mentions where and how materials should be returned to, to complete the cycle. It also mentions efficiency, use of clean and renewable energy sources and the role of governments and consumers. This definition will be used in this research as it is a thorough definition. It states the goal of CE, the importance of considering CE practices in all lifecycles is mentioned and both the technological and the ecological cycle are mentioned. Focus is also put on its impact on all levels, the need for renewable energy sources, the importance of resource efficiency and the active role of the government and consumers.

2.2.3 CE strategies

Nobre & Tavares (2021) mention the return of materials to an industrial process or the environment, while Kirchherr et al. (2017) mention ways of doing this, among others, via reusing and recycling. Potting et al. (2017) state nine different strategies for circulation within a production chain. The strategies are put in order of their effectiveness on making a production chain more circular. Interesting enough, the term 'recycling', which is often associated with an increase in sustainability and even mentioned by Kirchherr et al. (2017) is one of the strategies, which is deemed to be one of the less effective ways of increasing circularity.

The nine strategies are divided into three groups, where group 1 is considered the most circular and group 3 the least. The first three strategies are part of group 1 which focuses on smarter product use and manufacturing, meaning radical ways to change the product. The second group consists of five strategies which extend the products' lifetime. The third group focuses on the useful application of materials of the product. All these strategies mentioned by Potting et al. (2017) can be seen in Figure 1.

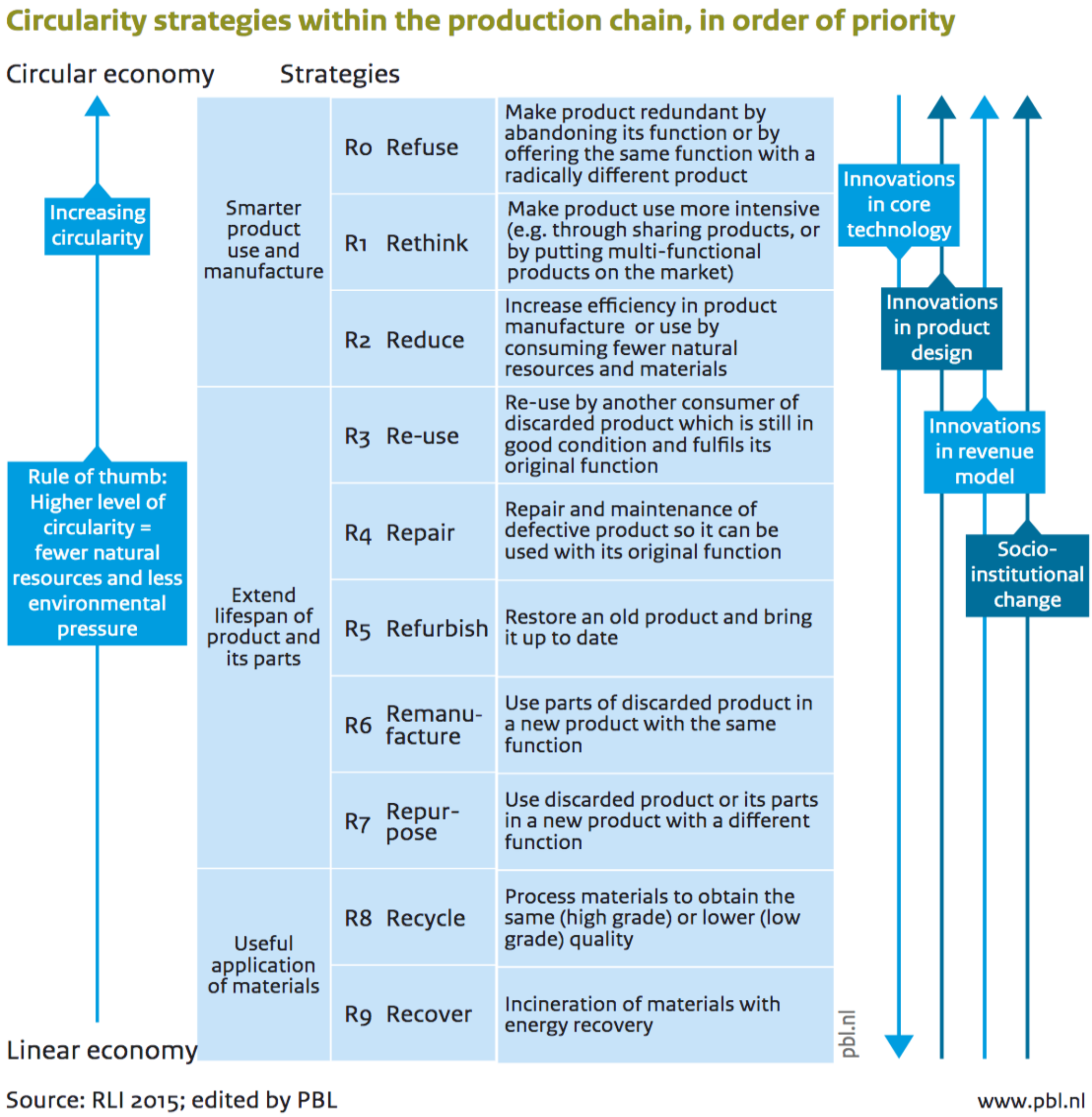

Figure 1, Circularity strategies in the production chain, (Potting et al., 2017)

Ellen Macarthur Foundation (2015) has laid out a framework, which shows how some of the strategies for circularity mentioned by Potting et al. (2017) are to be used in a biological and technical cycle (see Figure 2). The unused terms 'refuse', 'rethink' and 'reduce' are strategies which are part of the design phase.

The term 'repurpose' is also a method of connecting the product to another products' cycle and is also not mentioned in Ellen Macarthur Foundation's (2015) framework. The biological cycle considers biodegradable materials which are returned to the earth trough for example decomposing. The technical cycle considers products and materials which are kept in use in the economy trough for example reparations

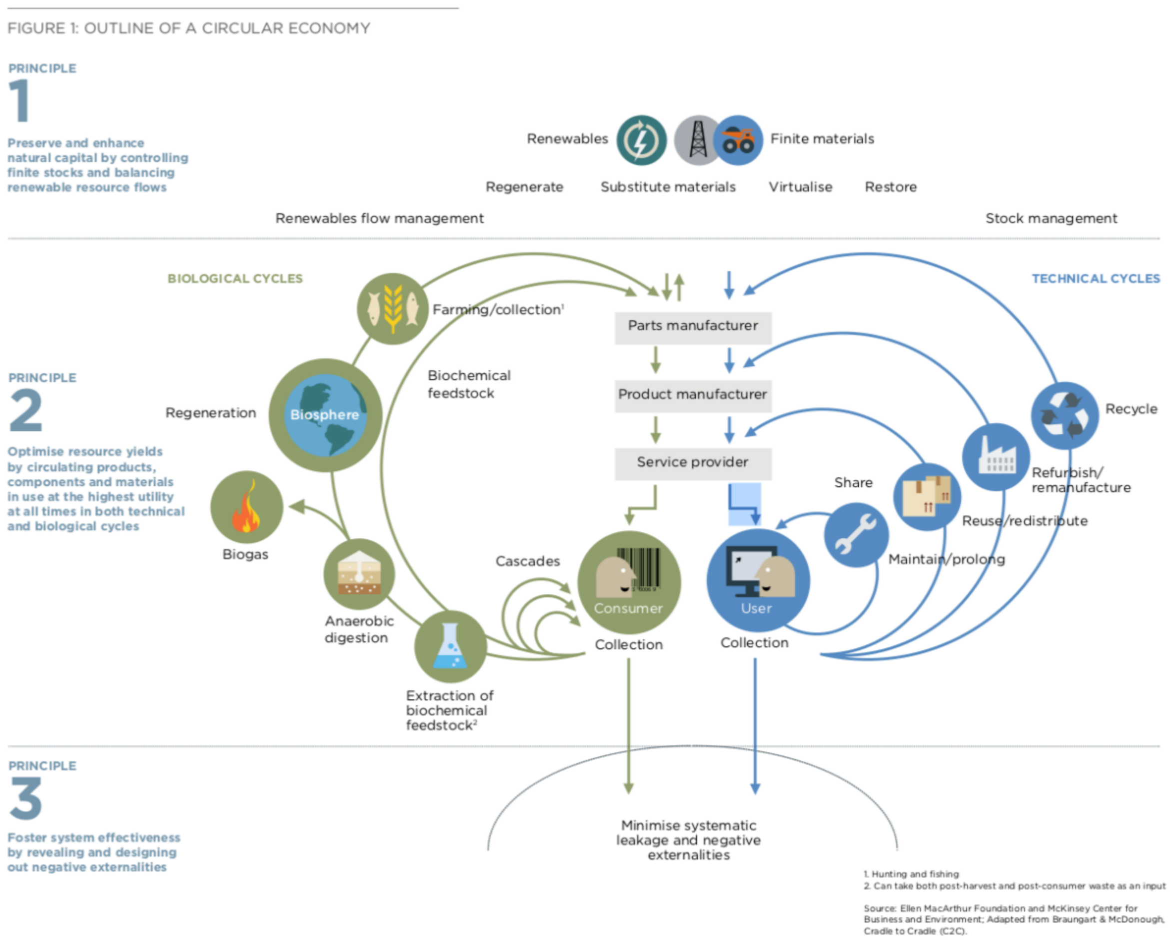

Figure 2, Outline of a Circular Economy (Ellen Macarthur Foundation, 2015)

2.2.4 Importance of design phase

According to EU Science Hub (n.d.), roughly 80% of the environmental effects coming from the product are determined in the design phase. Franco (2019) focuses on the impact of design when considering the lifetime of a product. It is shown that products with a short lifetime generate more waste. This is due to the obvious reason that they have a shorter lifetime, but also because these products are considered ‘used up’ and replaced faster than their lifetime.

De Kwant et al. (2021) point out the importance of integrating end-of-life strategies at the design phase of a product. They show this by researching the connection between CE and the electrical vehicle production industry. The increasing demand for electrical vehicles and the limited availability of poisonous materials such as nickel, used in the rechargeable batteries, create a problem for the long-term. If companies do not shift their focus more towards the design phase and start looking at other materials and methods for creating the batteries production companies will not be able to keep up with the demand.

Currently, Indonesia, the world's largest nickel miner, is increasing its production of nickel in an unsustainable way (Purdy, 2022). Problems occurring as a result of the nickel mining are deforestation, water pollution and decrease of life quality for local communities. This again shows that if sustainability is not considered in the design phase even sustainable products like electrical vehicles can become unsustainable (Purdy, 2022).

Asif et al. (2021) say more research should be devoted towards product design for all lifecycles like in a circular model. According to the researchers, circular design has unique factors which are currently not covered by the literature in terms such as 'sustainable design'. The few researches that are dedicated towards circular design frameworks are often generalized and based on linear systems. Hereby the framework is often 'reaction-based' where the framework is designed to make an already linear product more sustainable. For CE, a proactive framework is needed in order to support designers to create new circular products instead of changing linear products (Asif et al. 2021).

de Kwant et al. (2021) also state that there is a lot of research on CE but not on the importance of the design phase. Nyström et al. (2021) propose several methods how product design can become more circular. The first method is to design in such a way that the product can be updated and changed in all kinds of ways, without knowing how it's going to change beforehand. Meaning that your design should be adaptable and flexible. The second method is to maximize the products' lifetime by planning maintenance at the right time. The third method is to offer the product as a service, meaning that the physical product itself won't be sold but the use of the product will be sold.

This way the production company is responsible for maintenance and service the whole lifetime and therefore has incentive to do this properly. The last method is to design the product for different environments. Meaning the product will be used in different ways, extending its lifetime. In Figure 1 from Potting et al. (2017), the first mentioned strategies are 'refuse' and 'rethink', these are the strategies with the most impact into creating a CE.

Interesting enough, these two strategies do not evolve around reusing products or its materials. These two strategies focus on making a product usable in multiple areas, or more use intensive. This shows that when designing a product, the usage of a product should be maximized. Meaning that focus should not only be put on how to reuse products or its materials, but also on the actual need and usage of the product. This again shows how important the design phase is in order to achieve a circular business model.

2.2.5 Closing the loop

Bocken et al. (2016) further specify the importance of the design phase due to the fact that product specifications are hard to change after the design phase. Their article shows several strategies on how to design products in a circular way. Hereby two ways of affecting the loop in a CE are considered; 1), strategies for 'slowing the loop', and 2), strategies for 'closing the loop'. 'Slowing the loop' focuses on strategies which aim to prolong the use of materials by design. 'Closing the loop' focuses on reusing materials by design. One of the strategies in 'slowing the loop' is to design for attachment or for reliability.

Meaning that when a product is designed it should be designed either that it creates an attachment value so that the customer wants to keep it for a longer time, or that the product should be designed so solid that there is no need to throw it away. Another strategy for 'slowing the loop' is to design for maintenance, upgradability, standardization or reassembly. Hereby the focus is to design a product which can be repaired, upgraded, become compatible with other products or easily disassembled so that undamaged parts can be used again. In order to 'close the loop', the loop is divided into three different cycles.

1) The biological cycle, where products which cannot be recycled, should flow back to their natural biological systems. Here the products need to be designed with environmentally friendly materials which can for example be composted. 2) The technological cycle, where products which can be completely recycled are classified. An example of this is product as a service, where all products are maintained as long as possible and materials are reused when the product is replaced. 3), is a product which exists of both cycle 1 and 2, called 'monstrous hybrids'. For these products it is important that they are designed for dis- and reassembly. This way the technological and biological cycle can be separated, and proper recycling can be done.

After discussing how CE works in general, more focus will be put on how the building construction industry works with CE as a part of it and this is discussed next.

2.3 The building construction industry: An overview

This section gives an overview of the current state of the building construction industry. Topics covered are the set-up of a project, CE practices in the building construction industry worldwide and in Norway. Within Norway, deeper focus is put on successful projects, energy efficiency, contract forms and regulations.

2.3.1 How a building project is set up

There are several actors involved in a building project. In general, you have the building owner, the designers and engineers, contractors and building companies and manufacturers and suppliers of building materials and products.

The building owner is the person or institution which wants to construct a building. This can be everything from a private person to a big housing company. The building owner is responsible for acquiring enough capital, land and having a general plan for the building in terms of use and requirements for the building design. The building owner is not necessarily the end-user of the building. The building can be rented out to public and private parties or be managed by a facility manager.

The designers and engineers are the ones who create the building on paper. Here the rolls of building and landscape architect are relevant, as well as engineers specialized in heating, electrics and water. They get hired by the building owner and try to design in a way that meets the demands of the building owner. Demands can for example be, function of the building, number of users and maximum budget used. More sustainable thinking building owners might come up with demands such as number of second-hand materials used or amount of green energy used.

Contractors and building companies get contracted by the building owner in order to construct the building and technical installations. Their role depends on how much responsibility is given to them. In some cases, full responsibility is given from the planning phase till the building is build. When this is the case, they are in charge of acquiring materials, contracting specialists if necessary and constructing the building. In this case, they have an influence on how sustainable the chosen materials and the method of construction are, of course they are tied to a given budget. When given less responsibility, they can simply be contracted in order to construct something and only have influence on the construction method.

Manufacturers and suppliers of building materials and products are responsible for bringing their products to the building site when needed.
Another group which is to be considered are the demolition companies. These are the companies responsible for the destruction or deconstruction of a building at the end of its lifetime. These are not contracted until they are needed at the end of the building's lifetime (CA, 2020).

Adams et al. (2017) mention the challenge of a fragmented building industry. The current building industry is fragmented, meaning that architects design, constructers build and demolition companies clean up when the building is used up. The communication between the different contractors is minimal.

2.3.2 Current global circular practices in the building construction industry

Guerra et al. (2021) looked into the current state of circular practices in the building construction industry worldwide. Companies worldwide are starting to adopt circular strategies; however, this is still in the 'early-adopter' phase. Most companies which are indulging in circular practices are companies less than 10 years old and with fewer than 50 employees. Larger companies are also investigating the opportunities but are doing this merely to find new business opportunities and not as a part of their main strategy (Guerra et al. 2021).

There are some larger companies which have a core focus on reusing materials. Other big companies actively take over circular start-ups in order to develop them within the company. The larger companies are however putting more investments towards the research and development of circular business models. Several circular business models and their adaptiveness were also considered. ‘Using waste as a resource’, ‘resource recovery and ‘circular supplies’ are the methods used by most companies dealing with a circular strategy. These models are the easiest to adapt and therefore more widely used (Guerra et al. 2021).

In ‘waste as a resource’ business model, products are intentionally designed to use byproducts of other products. Resource recovery ensures that discarded materials are brought back into the system. Circular supplies focuses on building design existing purely of materials which are reusable, recyclable or biodegradable.

‘Sharing platform’ and ‘product as a service’ are more circular business models but less adapted. This is due to their complexity and how much a company needs to change their core business strategy. A ‘Sharing platform’ is a platform which provides the possibility of sharing a product which somebody owns to someone who wants to use but not own this product. An example of this is Airbnb, here a houseowner and a temporary house searcher are put together via the platform.

Product as a service is a business model, which offers the use of the product instead of ownership of the product. An example of this is printing services sold to companies. Nowadays companies buy printing services where a printing company provides the printers, its installation, repair and maintenance. The company does not own the printer but does get to use the printer in the same way as if it did own the printer.

The complexity explains why circularity is only increasing in popularity slowly. Circular strategies are complex and need to be properly understood in order to be adapted which takes time and money. It is also shown that technological developments bring new business opportunities. Blockchain, RFID and the Internet of Things can be used to increase traceability. Artificial Intelligence is used for waste sorting and 3D-printing can create a new form of online inventory. It is also shown that the theoretical knowledge is bigger than the current practical knowledge. In practice, it is also harder to collaborate with all partners in the supply chain, which is an important step in creating a circular business model (Guerra et al. 2021).

Adams et al. (2017) analyzed the CE awareness in the building industry in two ways: in the first analysis, groups were divided into clients, designers, manufacturers, main contractors and subcontracts. The second time, the groups were divided into types of organizations; manufacturers, researchers, consultants, designers and demolishers. The research shows that all companies have some employees with knowledge of CE, but that this is less when looking at the company as a whole and even worse in the building sector as a whole.

In the first group, the designers, clients and subcontractors showed the least knowledge of CE practices. This is a barrier in order to create a CE focused building industry as clients and designers are two important pillars for success. In the second analysis, focusing on the type of organization, showed that again designers had the least amount of CE knowledge.

In the Netherlands, the government has set a goal of becoming fully circular by 2050. One of the focus points is the construction sector. The Netherlands is already good on its way in becoming fully circular. The Netherlands has a circularity rating of 24,5% compared to Norway at 2,4%, Norway is therefore below the global level of 7,2% (CGRi, 2022;,2023). In the Netherlands, a transition team existing of experts from different disciplines in order to lead the circular transition within the building industry has been set up. They work together with both the industry and the government and give advice both when asked and when not.

Within the Dutch construction industry, there are four focus points set up in order to become fully circular by 2050. The first focus point is market development. Within market development innovative circular products, circular demand overview, an accurate action plan for 2050, a plan to make the current housing stock plus new housing circular and support of circular projects are considered. The second focus point is to create a common language in order to create a clear way of measuring circularity. The third focus point is towards policies, where stimulating policies open to international collaborations are required. The last focus point is to create circular knowledge, where enough people with circular knowledge need to be situated in the whole value chain (de Graaf, 2022).

Adams et al. (2017) researched barriers into creating a CE focused construction industry. The biggest challenge is the lack of proper end-of-waste regulations, especially demolition contractors found this an important barrier. Another challenge is the lack of regulation specifically focused on circular construction. New regulation should have a focus points such as planning and green public procuring requirements.

Currently, most policies on European level are mainly focused on recycling (Adams et al., 2017). This has a negative impact on CE practices as recycling often leads to downcycling and therefore limits the circularity of a building project. In order to push for use of more sustainable materials and ways of building, a CO2-tax can be implemented. A CO2-tax puts a price on CO2 produced during the lifetime of the building. This way incentive is provided for companies to produce less CO2.

2.3.2.1 The building industry's awareness and understanding of CE

Lack of CE understanding and awareness is seen as a challenge by (Adams et al., 2017). Between the different companies, it is unclear what CE exactly is and how to implement it. Some see CE as just another word for recycling, while other companies see it as a new way of doing business. Besides this, a lack of interest is also shown to be a challenge. In order to address these challenges, an information campaign specified for the building industry should be started.

An information campaign is a campaign which brings information on CE. It should involve a clear definition of CE, what it can bring economically to the company and what it can do for the environment. A roadmap on how companies with all types of functionalities can become more CE oriented should also be included. Extra focus should also be put on how secondhand materials can be reused without recycling, as recycling often leads to downcycling.

Wuni & Shen (2021) mention ways of becoming more aware on different levels. On an organizational level, employees should receive training in order to acquire more knowledge about CE. The employees with most CE knowledge should lead construction projects.
Companies need to change their business model in order to easily adapt CE practices. Construction companies need to understand the opportunities CE brings including

decreasing risk from CE projects, for example by creating long-term relationships with customers.

On a project-based level, the company needs to consider CE as a business strategy instead of a sustainability requirement. The building owner and design team should create an objective which includes CE principles in collaboration with its value chain partners.

In the planning stage, a building lifecycle approach should be used in order to see the full scope of CE principles. Already in the planning stage goals should be set on how much and possibly which CE principles are to be used. Integrated collaboration between all players is of the essence, in order to stimulate this, common financial interests should be pursued. From the start a commitment must be made to applying CE principles.

Early in the planning stage a demolition contractor should be attracted. They can judge the demolition and refurbishment possibilities of the project. A carbon, waste and cost consultant need to be part of the planning team. They need to identify the data and information which is needed for CE principles.

In the design phase, early CE commitment is vital, the building owner should arrange for all value chain partners to meet in order to improve communication and think about CE solutions. The value chain partners should also set CE goals for the project. The design team should collaborate tightly with its material suppliers in order to procure sustainable or secondhand products fit for the project. Waste, pollution and material usage should be minimized by designers. The building design should be designed according to flexibility, adaptability or other CE design principles. The building should be designed in order to be easily maintained, one way to do this is by designing in a modular way. For the procurement of materials, reverse logistics should be specified by the supplier, if possible, product as a service (PaaS) should be enabled.

Wuni, (2022) mentions cultural barriers for developing a CE in the construction industry. The most important barriers are: companies are hesitant and unwilling to change. In order to create a circular construction industry, different ways of thinking and doing business are required. Companies feel limited social responsibility and do not see the need for a circular change.

Besides this, the construction industry views secondhand materials as of less quality. Switching towards CE practices also increases uncertainty as they are still in development, meaning companies will avert these practices. Wuni, (2022) also mentions several knowledge barriers such as lack of CE knowledge and technical skills. In addition to this are management barriers, where lack of support for CE practices from top management is seen as the biggest barrier. CE practices are therefore not prioritized and integrated into strategic decisions, making it harder for lower management to employ CE practices Wuni, (2022).

Another barrier is the lack quality management for CE practices. CE is not measured and therefore not managed and improved. Due to the lack of CE activities, there is also a lack of CE technologies. Technologies which track, recover, separate and refurbish materials are needed. Without investments in these technologies a CE will be hard to develop.

Adams et al. (2017) mention the challenge of economic incentive. Companies do not often understand the financial profits a CE has to offer. CE is more seen as a way of making a project more sustainable and is applied if it does not cost too much. However, most CE initiatives strand due to lack of economic profit. There is a need to show how CE practices can be carried out in a profitable way. It is also mentioned that the initial investor of a circular building does not get as much profits as the final owner, which gives less incentive for circular designs. Wuni (2022) also mentions that profits by CE practices have not yet been demonstrated.

Creating a circular building industry is a challenge but creates opportunities in the form of new business models. One major change that has to be made is to look at total cost of ownership instead of the initial costs, which is currently often the case. Circular practices often require bigger investments but are profitable in the long run (de Graaf, 2022). Wuni (2022) emphasizes this by stating the lack of use of life cycle cost (LCC) calculations to get a financial overview of CE practices. Wuni (2022) also mentions the barrier of high startup costs. Because CE is not yet an established way of working, bigger investments are required.

Besides, there is also a lack of economic incentive for contractors to change towards a CE construction method. Contractors need to change their supply chain which costs extra. Unless the client pays extra for this change there is no economic incentive for contractors to change their ways. Poor allocation of funds is also mentioned as a financial barrier. Due to wrong use of funds, the success of CE projects has been varying.

Another barrier mentioned is the lack of short-term income from CE projects. CE projects have high startup costs and take long time to be earned back. For contractors only shortly involved in a project, this is unattractive. At last, virgin materials are often cheaper and better available than reused or renewable materials, which makes these materials less wanted (Wuni, 2022).

2.3.3 Current Norwegian circular practices in the building construction industry

The size of the Norwegian construction industry has been estimated at 513 billion NOK in 2021, this gives an increase of 2,6% compared to the year before. In 2024, the market is expected to grow towards 528 billion NOK, with the county of Oslo growing the most. The market-share with the biggest increase will be the investment in construction of new buildings (Macic, 2022). In 2020, there was 2 million tons of waste generated by the construction industry in Norway (Statistisk sentralbyrå, 2021). Miljødirektoratet (2019) states that the construction industry will need to adapt to alternations in the climate due to global warming. Increased chance of different kinds of extreme weather will need to be considered when designing new buildings.

Topnes & Sjulstad (2020) researched how much CE is adopted within the Norwegian building industry. The concept of CE had become familiar in the building construction industry due to non-governmental building organizations promoting the concept. However, what CE means exactly is still something which is different from company to company. Recycling and reuse of materials is how CE often is described. Although reusing materials is an important part of CE, it doesn’t cover the whole concept. It is also stated that trying to become more sustainable is often not found economically viable by companies. Some companies have adapted CE in their company strategy, although this is not always very visible in the actual projects.

Building Research Establishment Environmental Assessment Method (BREEAM) certification is a popular framework used in order to become more sustainable (Topnes & Sjulstad, 2020) BREEAM does not necessarily empower CE, but CE does empower BREEAM. BREEAM-NOR (BREEAM Norge) is the most used certificate in the Norwegian building industry (Grønn Byggalianse, n.d.). It was originally designed by the Building Research Establishment in Great Britain but has later on been adjusted to the Norwegian market. It is a certificate which focuses on nine areas: management, health and environment, land use and ecology, energy, transport, water, materials, waste and contamination.

A certified BREEAM-NOR inspector will check all prospects of these areas and give points per area. All categories need to be documented in order to receive points. All these points together will lead to a final score which will rate the building from 1 to 5 stars. BREEAM-NOR certification helps building companies in becoming more sustainable. For the building owners, it will increase the economic value of the building as customers are willing to pay for a more sustainable building (Grønn Byggalianse, n.d.).

Overall, Topnes & Sjulstad (2020) state the implementation of CE has not come far in the Norwegian building sector. Some buildings have been created based on CE, however, the majority of the building market does not have a big focus on CE. The design stage is one of the stages mentioned where CE practices are lacking (Topnes & Sjulstad, 2020) .

Methods such as Design for deconstruction (DfD), where a building is designed in order to maximize the reuse of materials after the building is deconstructed, are barely considered by companies. CE is not considered from the beginning of the design phase. The design is made and then it is checked whether some CE principles can be included.

Companies do focus on reusing materials. However, this is not considered from the start of the design phase in order to maximize reuse. This is considered and tested during the construction phase. Focus is however, put on trying to use environmentally friendly materials. Suppliers and manufacturers of building materials and products do not focus on designing products for standardization or easy deconstruction. This also shows that there is no market based on a ‘product as a service’ model, which gives incentives for producers to create more sustainable products.

Furthermore, in the construction phase, waste management has been lacking (Topnes & Sjulstad, 2020). Few firms have requirements towards the amount of waste per square meter. And those who have, are having troubles upholding these standards. Methods to reduce the created waste are sending it back to the suppliers or reusing it. Topnes & Sjulstad (2020) again point towards a lack of focus on this in the design phase.
According to Topnes & Sjulstad (2020), a long-term circular vision is lacking. Long-term planning in order to maximize reuse of materials both when constructing and deconstructing a building is missing. The buildings which are standing today are not designed with circular aspects. Maintenance, upgrades or easy building changes are therefore hard to realize and also principally nonexistent.

Material databases are still under development, although start-ups are coming along and some companies are starting an internal material bank, this is not yet an industry-based standard. An internal material bank is a storage of materials and products which come from old building projects and are quality checked to be reused. The current form of the Norwegian building industry is very shattered. For CE practices to be implemented, supply chain cooperation is essential. Due to the current shattered form of the building industry, CE practices are not being implemented where they could have been.

Currently, companies are at the phase of realization that cooperation is necessary to reach climate goals. Some companies have also started calculating the environmental footprint for the whole lifecycle of a building in order to make more sustainable choices. Calculating whether it is more sustainable to rehabilitate or demolish a building is also considered more often (Topnes & Sjulstad 2020).

Stein Stoknes, head of FutureBuilt mentions different challenges in order to make the building industry more circular. There is a need for both digital and physical marketplaces for reused materials (Backe, 2019). A digital overview of materials used in buildings currently standing is required. Besides this, the deconstruction company needs to scan the building and let the market know which materials will come up for sale (Backe, 2019). The current state of CE in the building construction industry in Norway will be further explained in the section below with examples of CE projects in Norway. In the following section a couple of successful CE construction projects are highlighted.

2.3.3.1 CE projects

Angvik Eiendom, which has its headquarters in Molde, manages around 150.000 square meter divided over 50 buildings in Molde has teamed up with Madaster, a company which creates a digital overview of all materials used in a building. From these 50 buildings Angvik Eiendom wants to measure the materials' carbon footprint and their remaining lifetime. These materials can be put into a material bank, which can be used in buildings that are still to be designed (Blakstad, 2023).

In Oslo, a company called Veidekke, has started the first project in Norway where circular concrete will be used throughout the whole building. The goal is to have a greenhouse gas reduction of 50% compared to similar buildings (Midttun, 2022). There are also whole towns who want to transform into a smart city. One of the pillars for this is circular building design. The goal is to create a living area which empowers people to go outside and live a healthy life. Building and other projects which need to be built for this are aiming for circular design and construction. Examples of these projects are Circular City Bodø 2.0 and Powered by Ulsteinvik (Felixx, 2020; Prosdocimo, 2021).

KA13 is a building in Oslo which received the government's award for building quality in 2021. It is the first building in Norway which has reused materials and applied circular practices on a big scale. Almost all materials used are materials which would otherwise have ended up as waste. The amount of waste has been significantly reduced by reusing buildings from both existing and deconstructed buildings. The original building from 1950 which was standing there has been renovated instead of demolished. The rain falling on the rooftop is captured to water all the plants. The plants are chosen to attract pollinating insects (Asplan Viak, 2021) .

FutureBuilt (2023) has set up a framework with requirements circular buildings should have. First of all, it should be considered whether a building should be rehabilitated or deconstructed. If it is deconstructed, it should be done in such a way that resources can be reused in the most efficient way. When the new building is constructed, it should be considered what the most efficient way to construct a building while reusing resources.

When designing a building, there should be thought about how the building can be transformed in order to change the use of the building in its later life (Backe, 2019). In Oslo, a storage place has been started for high quality used materials from old buildings. The space will be 4500 square meters and will function as both a storage and pick-up place for used materials. It will be a pilot project to see how this works and which challenges arise (FutureBuilt, 2023).

In the following section, regulations relevant to CE in the construction industry are discussed.

2.3.3.2 CE regulations in Norway

In 2022, new laws were put in place making it easier to reuse materials. A barrier for reusing materials was the amount of complicated documentation. For example, it was expected to have knowledge on the production method of the materials. As not all building owners know this, the materials become difficult to sell. Almost all documentation has now been removed making it just as easy to buy reused as new materials (distriktsdepartementet, 2022).

Moreover, a law is in the making about the requirement of greenhouse gas calculations in the building industry and new requirements for building materials are to be introduced. The new proposal also mentions that governmental support in order to create material banks is necessary and that produced waste should be streamlined and digitally documented (Stortinget, 2023; Solheim, 2022). An increasing focus is also going towards waste flows. The requirements for waste-separation increases from 60% to 70%. Besides this, a new requirement is that building projects with more than 10 ton of waste, need to separate all waste, create a waste-plan and final waste report (Holm, 2022).

Norwegian frontrunners of a circular building industry are not yet satisfied with these new laws, as they feel material requirements are missing. A regulatory framework surrounding the requirements for reduced emissions per square meter is yet to be developed. There is quite some knowledge on which materials increase greenhouse gases, but little knowledge on which materials reduce greenhouse gases (Arkitektnytt, 2013).

A maximum requirement for emissions linked to material use would have been a good starting point. In addition, a public platform should be provided, where old materials can easily be registered (Arkitektnytt, 2013).

Enova is a support organ set up by the government. It provides economic support to projects which will help to reduce greenhouse gases and develop new technologies. In 2021, Enova provided 4.6 billion NOK towards all sorts of projects (Enova, 2022a). One of the focuses of Enova is the building and property sector. In 2020, Enova provided 290 million NOK towards this sector divided over 268 projects with a calculated reduction of 0.21 kilo ton CO2 (Enova, 2022a).

Currently, the focus of Enova is on two types of projects within the building and property industry. First, a feasibility study for reuse and flexibility of materials, and second, project planning for reuse of materials. Both small and big companies can acquire this support in order to create a more circular material flow within their building project (Enova, 2022a; 2022b; 2023).

Furthermore, collaboration is key for a successful transition towards a CE building industry. Both value and supply chain initiatives are important. For example, trying to work together in order to create more sustainable materials. Governmental support is vital for these collaborations. The Netherlands has put a goal of becoming a fully circular economic nation by 2050 and has made a plan and put up a team of experts to guide this plan.

Norway has set goals of becoming a green economy, but not a circular one (Regjeringen.no, 2020). CE is seen as a method for creating a green economy, but not as a goal in itself. This shows that the Norwegian government is motivated to change, but not as much as the Dutch government (Regjeringen.no, 2020; de Graaf, 2022).

Next, energy efficiency in the Norwegian construction sector is discussed. Focus is put towards regulations and successful projects.

2.3.3.3 Energy efficiency in Norway

In Norway, Enova provides economic support for companies and private persons wanting to make their building more energy efficient. Support is offered for things such as extra isolation, producing your own electricity and renewable heating sources (Enova, n.d.). The building industry is responsible for 34% of the total energy consumption in Norway (International Energy Agency, 2022).

The main measure taken in order to reduce energy use is the in 2010 added building certificates. These certificates are a measure of how energy efficient a building is. The certificate rating is given based on energy efficiency and heating rating (International Energy Agency, 2022).

Beside this, the government has prohibited the installation of fuel-based heating systems since 2016 and the use of heating oil since 2020 (Norwegian Ministry of Petroleum and Energy, 2019). Norway's electricity generation is almost 98% renewable based. Although Norway is very well off with their current energy structure, it also needs to adapt to the future. More energy generators are needed to comprehend growth. Additionally, cost savings could be made by reducing consumption. A great example of this is the Powerhouse described below (International Energy Agency, 2022; Norwegian Ministry of Petroleum and Energy, 2019).

The European Union has decided that the new buildings built from 2020 onwards are to be near zero energy buildings. Meaning that the amount of energy produced by the buildings must be close to equal to the energy usage. In the Oslo region, the population is expected to grow by 40% in 2050. This means new houses need to be built, but in a sustainable way (Green Visits, 2019). FutureBuilt is a project started by the Oslo municipality partnering with neighboring municipalities. It is a 10-year project that started in 2010 with a goal to build 50 pilot projects in a sustainable way (Green Visits, 2017).

One of these projects is Powerhouse Kjørbo. There are currently three Powerhouse buildings in Norway. For Powerhouse Kjørbo, two office buildings from around 1980 were redesigned in order to become more energy efficient. The building was redesigned in such a way that the energy demand dropped by 85%. The structure of the building remained and several materials such as glass and concrete were reused. Windows from the original building were used as doors and walls in the renovated building. Solar cells were put on top of the building and provides 210.000 kWh per year. The building only needs 100.000 kWh per year and thus produces a surplus which is being used in another building nearby (Green Visits, 2015). The following section will describe the contract forms of the Norwegian construction industry and its appliance to CE principles.

2.3.3.4 Contracts in the Norwegian building construction industry

Hosseini et al. (2016) conducted a research on how partnerships are developed in the Norwegian construction industry. The research shows that there is no clear definition on what a partnership actually is, and what kind of obligations and benefits come with a partnership. It is also shown that there is no specific requirement for becoming a partner nor do companies have their own standards for the requirements in order to become a partner. The lack of a partnering culture makes it harder for companies to work together. In the case of a circular business model this is something that needs to change.

In order to make agreements on services and products and at what price contracts are closed between different actors, there is a set of standard contracts which can be used for different scenarios between different actors. These contracts can also be adjusted to specific scenarios if necessary. These contracts are called Norwegian Standard (NS) contracts. In Figure 3 below, an overview of which contract to use in which situation is given (Standard Norge, 2020)

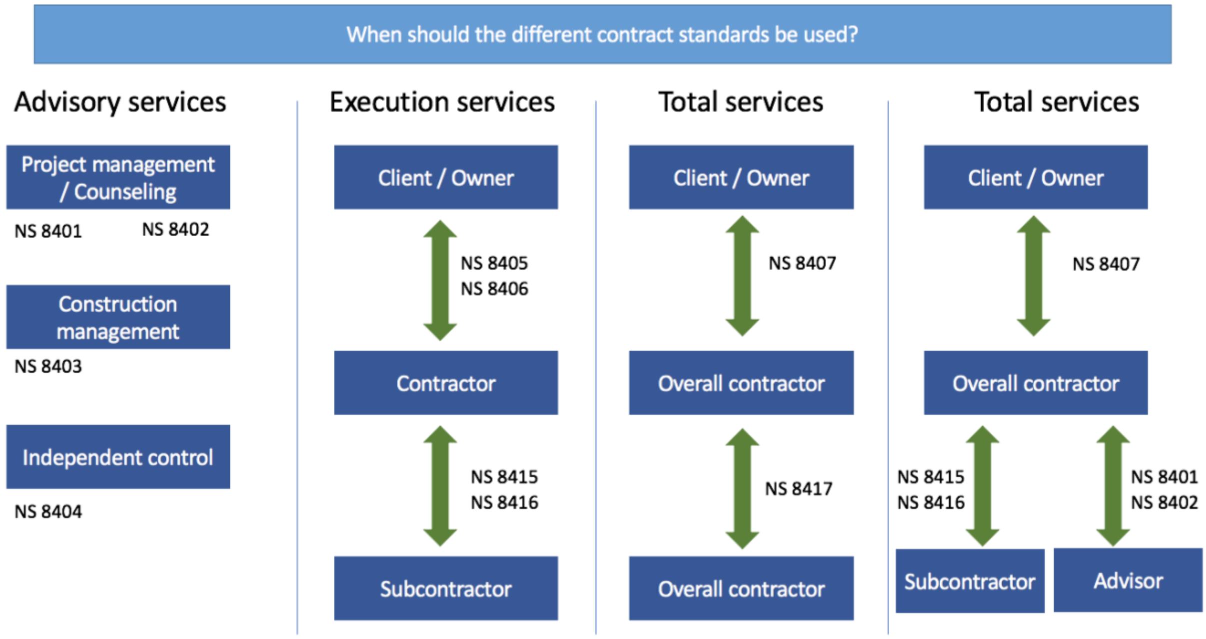

Figure 3, Overview of contract forms in the Norwegian building industry based on (Standard Norge, 2020)

A problem with this form of contracting is the lack of teamwork. When a building owner contracts another actor, for example, a material supplier, they are given the assignment of delivering the wanted materials to the building owner. However, the materials chosen by the building owner or the design team may not always be the best choice for that building due to economic or environmental reasons. Material suppliers are not involved in the design phase. Suppliers have more knowledge on their materials and could thus be of help in the design phase, by picking materials fit for certain occasions.

In the Norwegian building industry, this has led to changes in the current standard form of contracting. One form of contracting which has become more popular is called 'collaboration contracts'. These contracts are based on the fact that designers, engineers, construction companies, material suppliers and product manufacturers are involved as early as possible in the project. It requires strict communication between all actors during the whole project. The contract is built upon mutual trust and openness. This is relevant for all involved actors, both in financial settings and technical solutions. The involved actors need to have common goals and common financial interests.

The collaboration contract can be set up in multiple ways, but these are two most used, collaboration for total enterprise and interaction with incentive (Eder, 2019). The first one is characterized by the fact that all actors work together until the planning phase is finished and a target price is set. The target price is the price which all actors agree that the project can be finished for. This is used as a basis for the new contracts made per actor. The second one is characterized by cooperation up till the planning phase. Meaning, a target price is set and contracts are made based of work percentage towards the set target price. By doing this total economic and environmental savings can be achieved with less effort. These contracts require that all actors, including sub-actors are included as early as possible. All actors must also have trust in the contract. The building owner has the responsibility of keeping close contact with all actors during this period.

Currently there is no standard contract for the collaboration contract. Rather it is based on the fundamentals of the total enterprise contract (NS 8407). Changes in this contract need to be made in different areas. Notification rules are replaced by more flexible rules in order to reduce resource intensive processes which have a negative impact on the project and collaboration. Changes need to be made related to the set target price and agreed amount of work done. Conflict rules need to change in order to quickly dispute of possible problems.

Risk distribution rules need to be changed in order to change focus from personal to group risk. Contracted actors need to be paid based on a ‘open book’ model. Where an actor shows their actual cost, which are covered by the building owner. Besides this a bonus is given for the amount of work done in relation to the price target (Eder, 2019) .

FutureBuilt has established guidelines in order to ensure that contracts are directed towards circular building design. First, focus should be put on using rental agreements instead of purchasing. This way the material supplier will remain owner of the materials and therefore have incentive for reusing the materials. Second, return programs should be set up with suppliers. This will make it easier to return materials after they are used (FutureBuilt, 2022). Adams et al. (2017) also mention the importance of performance-based contracts and how these could help with CE practices.

2.4 Lifecycle stages in the building construction industry

2.4.1 Lifecycle stages in the construction industry

Bahramian & Yetilmezsoy (2020) compared over 200 articles related to the lifecycle assessment of the construction industry. It is shown that in these articles different kinds of lifecycle stages are used. Several articles used the following definition consisting of four stages; 'materials manufacturing', 'construction', 'use and maintenance' and 'end of life'. 'Materials manufacturing' considers the gathering of raw materials, the transportation of these materials, the production of building materials and products, and its transport. 'Construction' considers all activities which happen during the physical building phase of a project. 'Use and maintenance' regards the use and maintenance of water, energy and waste systems. 'End of life' considers the energy and waste produced in the demolition phase of a building. And how this waste is transported and disposed.

Another method of dividing the lifecycle stages is also mentioned. This method focuses more on the environmental factors and is as followed; 'product', 'construction process', 'use', 'end of life' and 'benefits and loads beyond the system boundary'. 'Product' is made up of three different phases. The extraction of raw materials, the transportation phase and the production of new materials and products. 'Construction process' regards the transport of materials and products towards the physical construction project and its insertion into the construction.

The 'use' stage considers the fixing of problems to the building by repairing or replacing materials. The operational energy use is also considered. 'End of life' considers again the destruction of the building and its waste handling. The final stage 'benefits and loads beyond the system boundary' considers the environmental footprints which are not directly accounted for in the construction of a building. The second definition is a newer one and focuses more on the environment. It focuses not solely on the direct environmental impacts but also the indirect ones.

2.4.2 Lifecycle stages in the circular building construction

Büchele & Schober, (2021) use the following lifecycle phases for circular construction; 'plan and design', 'procure', 'construct', 'operate' and 'end of life'. The 'plan and design' phase considers how the construction will become a circular product. Here, methods of how to reduce the buildings ecological footprint will be discussed. The 'procure' phase will consider how the materials will be acquired. Focus is put on material reuse, and if raw materials were to be used, they need to come from renewable sources.

The 'construct' phase focuses on how the construction can be built in a circular way. Techniques like 3D printing and prefabrication can be used. Besides this, focus is put on minimizing and reusing waste. The 'operate' phase is used to think about how the construction is going to be used in order to maximize its utilization. This can be done organizing different kinds of activities during the day and night or by offering the building as a service. Smart software solutions are considered in order to minimize energy use. The 'end of life' stage focuses on maximizing the life of a construction trough smart maintenance. When a building needs to be deconstructed focus is put on how the materials can be reused or upcycled. All lifecycle stages are shown below in Figure 4.

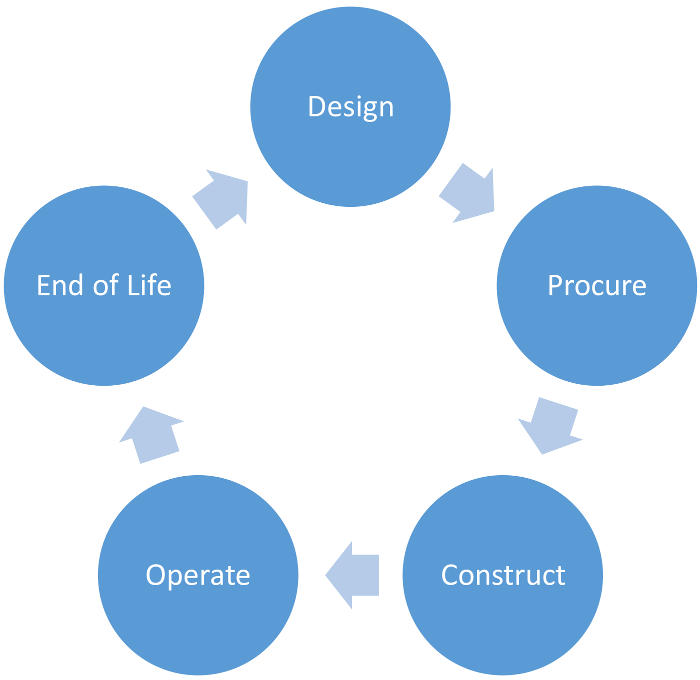

Figure 4, Circular lifecycle stages, own illustration based on Büchele & Schober, (2021) All lifecycle stages need to be considered during the 'plan and design' phase. The point of circular construction is to design and build something which can be reused. In order to maximize the 'reusability' of a construction, all lifecycle stages need to be connected together. It is not possible to first design the building and then later start thinking about where the materials will come from or how the building will be used. All these are interconnected and should be looked upon as a part of the 'plan and design' phase. A further focus is put on the circular lifecycle stages in the following sub-chapters, starting with the design phase.

2.4.2.1 Circular design phase

de Graaf (2022, p22) define circular design as follows, "Circular design pre-integrates lifespan considerations, and future reuse of materials and structures at every stage of the project". Currently, buildings have often been designed for a specific use case. However, as the use of the building changes over time, the building becomes less attractive. Therefore, it is necessary to design buildings which can adapt to future needs.

For example, FutureBuilt (2022) advises to design for adaptability. This means that a building is designed in a way that it can easily be changed to the wishes of a new client. Here the three focus points are generality, flexibility and elasticity. Generality focuses on easy accessibility of rooms and even daylight distribution. Flexibility ensures that both interior, walls and its technical systems are easily adjustable. Elasticity focuses on the changeability of rooms and its technical systems when extending either horizontally or vertically (FutureBuilt, 2022).

According to Adams et al. (2017), another challenge mentioned is the complexity of buildings. In order to solve this, more standardized and simple designs could be created. The goal of end-of-life design should be to create a maximum lifespan of the building and its materials through smart design and maintenance. Another circular design method is design for deconstruction. This method focuses on how the building design can maximize both the quantity and the quality of the materials which can be reused at the end of a building's lifetime (Bre Group, 2015).

Another method is design for modularity, this method focuses on designing a building in modules, which can easily be installed, replaced and taken apart. One way of supporting this is by using prefabrication as the construction method instead of regular on-site construction. With prefabrication whole modules can be built in the factory and then quickly installed on-site (American Institute of Architects, 2019) .

Another method is to design out waste. In this method, focus is put on nullifying waste in every step of the lifecycle stages (Zero Waste Scotland, 2019). Two other design methods are: specify reclaimed materials and specify recycled materials. The concept of the two is similar but as one focuses on recycling of materials the other one focuses on the reuse of materials. In these methods, the building is designed with reused or recycled materials as much as possible (Greenspec, 2005; Zero Waste Scotland, 2019).

Ness (2020) states that the current focus on energy efficiency is not enough to reach the 2050 climate goals. The research states that by building nothing or building less a carbon reduction of 80-100% can be achieved. To build nothing or less a new way of thinking should be considered in the design phase. For every building which is planned, it should be questioned whether this is really necessary or if there are more sustainable alternatives, like redesigning an old building. This will require a change towards a more service-oriented mindset. From the governmental side, a carbon tax will force companies to change their mindset due to increasing costs of building more.

2.4.2.2 Material procurement phase

There are several ways to make more environmentally friendly use of materials. One method is to substitute environmentally unfriendly materials with environmentally friendly ones. Another method is to produce already used materials in a more environmentally friendly way. And third, it is also possible to reuse old materials from other buildings (Backe, 2019).

In Norway, a new tax has been introduced for burning waste. Besides this, an extra CO2 tax is expected. Prices have increased due to both the war in Ukraine as and belated deliveries from outside of Norway (PricewaterhouseCoopers, 2022). These are economic factors which have pushed for a bigger interest in reusing materials. Reusable materials are less dependent on outside market influences. Higher energy prices, a war in a different country or another unexpected event does not affect the price of reusable materials as much as new materials. Companies are therefore looking at the secondhand market, not only due to environmental interest, but also due to economic interest (Soldal & Sjøvåg, 2022).

First of all, there are delivery risks. In Norway, most materials are delivered shortly before being needed and have long transport distances. The longer the transport distance the bigger is the impact of a distortion in the supply chain, both pricewise and in delivery time and security.

The price of raw materials coming from outside Norway are also a risk factor. Steel and cement products were imported for a worth of over 3 billion NOK in 2017, about 20% of the total import value of the building industry (Soldal & Sjøvåg, 2022). Other materials being imported are bitumen and wood materials, being responsible for about 4% of the total import value of the building industry. The price of bitumen has increased with more than 20% since 2022 and wood materials rose with 30% on the Russia invaded Ukraine.

A third risk is the risk of a changing regulatory framework. Norway is slowly headed towards a CE, and the regulatory framework will change in order to speed up this process. Making long-term deals on raw materials might let you end up in the middle between a circular regulatory framework and the ownership of raw materials which does not comply with this framework. Reusing materials will make a company less dependent on sources coming from outside Norway, and its complying risks (Soldal & Sjøvåg, 2022).

In a study conducted by Arkitema (2022), it is shown that wood can be an economically viable substitute for concrete and steel. In Scandinavian countries, a lot of houses made from wood can be seen. On the other hand, bigger wood-constructions are not as popular. In the building industry, the common understanding is that wood is more expensive to work with than concrete and steel. The type of project which is being designed has a lot to say whether you can use wood in an economically viable way. Material-cost is often higher when making a building out of wood. However, foundation and construction costs are often lower when using wood. Wooden buildings weigh less and require therefore less foundation, and the building time is also decreased. The logistics of a wooden building is also different and requires careful consideration. When experience is built up with creating wooden projects, costs will also lower. Wood is a material which can be considered in the design phase of a building to decrease both costs and environmental impact. It is important that it is considered from the design phase on, due to its different method for logistical and building processes (Arkitema, 2022).

FutureBuilt (2022) shows different methods in order to improve material selection for circular buildings. The first focus is to keep the variety of chosen materials to a minimum. If less types of materials are used, it is easier to reuse them in another building due to more availability. Second, is to pick products which are made up from the same materials. If similar materials are chosen, it is easier to reuse them due to their similar lifecycle. Third is to pick materials which can be reused in multiple building lifetimes. Fourth is to reduce materials which can be hazardous to health or environment. Fifth is to employ easy usable parts and create modular designs, made up of multiple smaller parts easy to disassemble.

FutureBuilt (2022) has also come up with tips in order make it easier to make use of circular practices. The tips focus on flexible connections as this makes it easier to disassemble building parts and therefore reuse them again. First tip is focused on the use of reversable connection parts between building segments, make no use of foam or glue-like materials. Design so that standard tools can be used and minimize the number of connection methods. Use building products which are fit for dis- and reassembly. Design different building layers as individual layers and organize them according to their life expectancy.

A lack of willingness to design products for the end of life is seen as a challenge by Adams et al. (2017). Materials and product suppliers need to have some form of responsibility for their products. A return scheme could be a solution for this. However, this won't work for all types of products due to lifespan, so different solutions need to be created. Another challenge mentioned is a lack of a secondhand market which stimulates the recovery of materials. Financial incentive needs to be created in order to create a market attractive for the building industry. When this market is created it gives the following challenge which is that the supply and demand needs to be matched. This is a bigger challenge than in a virgin materials market. A method of solving this could be by setting up proper return or assurance schemes.

In the Netherlands, a tool used to create a more circular procurement process is the environmental cost indicator (ECI) (Hilege, 2019). It is an indicator which puts all environmental costs across the value chain of a product into a single number. Products with a good (low) ECI rating become more attractive to procurers, even when a product is more expensive. As an example, the government needs to have a new building. Building number one has an economical cost of €90 million and an ECI of €40 million. Building number two has an economical cost of €100 million and an ECI of €20 million. The government will choose building number 2, which is economical more expensive but cheaper for the society, because the price includes environmental costs. Thus, the ECI gives incentive for producers to create more sustainable products, even when these are more expensive (Hilege, 2019).

Measuring circularity is an important step in creating a circular industry. In the Netherlands, a national database has been created where the circularity of materials is shown. The circularity value is based on three factors. 1; How much does it protect the current stock of materials, 2; what is its value towards environmental protection, 3; how long does it keep its value (de Graaf, 2022).

Product as a service (PaaS) is a circular business model which needs to be considered in the building industry. PaaS gives suppliers incentive to create materials which are long lasting and fit for reuse. However, within the building industry this can be a challenge. The long lifetime of building makes PaaS less fit (de Graaf, 2022) . Circular marketplaces need to be existent for a circular building industry. Just as in a normal building marketplace there would be need of raw and building materials, however these materials would now be second hand. Additional activities at the marketplace could be separation of waste and demolition materials and repurposing this waste into materials (de Graaf, 2022). Wuni (2022) mentions the barrier of uncertain demand for reused products. A lack of a well-functioning circular market is a barrier when trying to transition from theory towards a CE construction industry.

de Graaf (2022) discusses the most used building materials, concrete and steel. Concrete is the second-most utilized material in the world, second to water. Concrete is used so much in the building industry because it is easy to shape, has a long lifetime and is resistant to water, fire and compression. During the production of concrete, cement is used which is a highly CO2 emitting material. Besides this, it consumes a lot of water and energy in the production phase and is expensive and difficult to reuse.

Steel is also used a lot due to its long lifetime, flexibility and high density which allows for the production of lightweight buildings. About half of the world's steel demand comes from the construction industry. Steel produces about 1.85 tons of CO_2 per ton which totals up to about 8% of the global emissions. However, steel is 100% recyclable and keeps its original properties when reused. It is an energy consuming process to recycle steel though. In order to increase material efficiency in the building sector, two methods are available; focus on reuse of materials and focus on different, renewable, materials. Bio based building materials can be a new source of building materials. Bio based materials remove greenhouse gases from the air. When used right, bio-based materials can create a positive greenhouse gas result.

When reusing materials several challenges are faced. First of all, there are technical requirements and laws which need to be followed when purchasing used materials. It can be a challenge for used materials to fulfill the standards of today's society considering isolation, fire-safety and energy friendliness. Not only today's standards need to be met, but also the new standards 20 years from now (Miljødirektoratet, 2018). Besides, Charef et al. (2022) mention a limit on how often materials can be reused. In a fully circular context, all materials would be reused and no waste would be created. However, materials do decrease in quality over time and might need to be thrown away. How this waste is handled is key to creating a circular process. The researchers mention the decay of bricks, but these can be made into new bricks as well (Business Waste UK, n.d.).

2.4.2.3 Construction phase

One of the goals of the construction phase is to build while producing as little waste and CO_2 as possible. This can be achieved in several ways: The building can be designed via the design out waste principle. Design out waste means the design team designs the building in such a way that waste is minimalized. This can be done by choosing higher quality materials, off-site construction and waste efficient procurement (StoneCycling, 2021). Besides, a waste plan could be created, where waste reduction should be the goal. For the waste that is generated, a following plan is made; it starts with getting an overview of all materials and how to reuse these materials. Between the value chain partners, it should be known who takes responsibility for which waste (StoneCycling, 2021).

Off-site construction is when a building or parts of a building are built in the factory and then transported to the on-site location. Off-site construction can exist from a single wall to a whole building. A lot of different materials such as wood, steel and concrete can be used. The advantages of off-site construction are shorter construction time, more predictable cost, less waste generated, less CO2 emissions from day-to-day transport, less on-site disturbance and more safety for workers (Smith, 2016).

Although waste is significantly reduced, the biggest environmental improvement is less day-to-day transport. The downsides to off-site construction are less design possibilities due to factory and transport limits. 3D printing is another technique which can be used in combination with off-site production. In 3D printing layers of a certain material are printed on top of each other in order to create a certain shape (Smith, 2016; Miles, 2020).

FutureBuilt has come up with tips in order make it easier to use circular practices. The tips focus on flexible connections as this makes it easier to disassemble building parts and therefore reuse them again. First tip is focused on the use of reversable connection parts between building segments, make no use of foam or glue-like materials. Design so that standard tools can be used and minimize the number of connection methods. Use building products which are fit for dis- and reassembly. Design different building layers as individual layers and organize them according to their life expectancy (FutureBuilt, 2022).

This is another tip that FutureBuilt (2022) has come up with in order to make it easier to make use of circular practices. First tip is to label building components with the type of material it is and where the assembly point is. Second, is to create a material passport of the building. A material passport shows which materials are used in the building and how these can be disassembled. Last, is to create a digital twin of the building for example using building information modeling (BIM), which gives an overview of all materials and where they are used in the building (FutureBuilt, 2022). Adams et al. (2017) further specifies the importance of BIM. Besides this, the importance of a circular decision-making framework across a building's lifecycle is mentioned.

2.4.2.4 Operating phase

Approximately 85% of the CO2 footprint of a building is created in the operating phase, also known as use phase, compared to 13% in the construction phase and 2% during the demolition phase (Peng, 2016). Strategies in order to decrease this footprint should be thought of in the design phase. These strategies should focus on energy efficiency and material resource impact (de Graaf, 2022).

To achieve energy efficiency, focus should be put on insulation, green energy production, natural light and warming and reduction of total energy use. These parts should be thought of when designing a building. Green energy production could be achieved through solar panels on the roof. Natural light and warmth can be achieved through more open windows pointed towards the sun (Aeroseal, 2019).

To extend the lifetime of a building, its materials and components, asset management is of importance. Asset managers can plan maintenance activities in such a way that materials and structures have a prolonged lifetime. This will not only increase the lifetime of materials but also its value in a second hand market, providing economic incentive to have proper asset management (de Graaf, 2022).

Cooling, heating and lighting sensors help in order to see where energy should be used and where less energy is used. These sensors can cut down energy use and detect patterns in order to maximize comfortability (Raphy, 2020). In order to make sure a building can be used for different purposes over a longer period of time, adaptability is important. The building should be designed in a way such that it is easy to change walls, rooms, etc. to the likings of a new user (FutureBuilt, 2022).

Vertical farming is the process of farming, such as growing vegetables, inside a building. Vertical farming is sometimes mentioned as a way to reduce CO2 emissions around buildings. Plants can take in the CO2, decreasing the CO2 footprint. However, vertical farming uses a lot of energy. Vertical farming uses about 8 times more kWh per kg of produced goods. If vertical farming were to be employed in a building, renewable sources have to be used, otherwise it loses its value. On the other hand, vertical farming emits less CO2 due to reduced use of tractors and other machines and shorter transport.

Besides, both land and water use decrease with about 85% (Maglio, 2023). Water harvesting is also a method which can create a more sustainable building. Water scarcity will only increase over time, so water needs to be reused. Catching rain from rooftops and filtering it to be usable can be a way to do this (Raphy, 2020). Energy efficiency can also be increased by new business models such as pay-per-use. Lighting systems are installed while the company providing the lighting remains the owner. This way the lighting company has incentive to create a lighting system which holds as long as possible and can be reused over and over again (Raphy, 2020).

2.4.2.5 End of Life phase

In a circular end of life phase, more focus is put towards sustaining materials in their original state. Currently, most buildings are demolished creating big amounts of waste and little amounts of reusable products (Bertino et al., 2021). In 2021 approximately 760 thousand tons of waste was generated in the demolition phase, this is about 42% of the total waste generation in Norway (Statistisk Sentralbyrå, 2022). Deconstruction is a method which focuses on keeping products as a whole or at least in a state where they can be used again.

For deconstruction, there are two types (Bertino et al., 2021): structural deconstruction and non-structural deconstruction. Structural deconstruction is the deconstruction of essential building parts which keep the building stabilized and in place. These are products such as pillars and walls for load-bearing components. These parts of a building are harder to deconstruct, take longer and are not always possible due to design. Therefore, design for deconstruction is important for future buildings. Non-structural deconstruction focuses on products which are not responsible for the stability of a building, such as windows and doors. Non-structural products are easy to extract and take less time.

Moreover, it is also easier to reuse non-structural products due to a market availability. First non-structural products are deconstructed, second are the structural parts. For proper deconstruction, a selective order must be followed. First technical installations, second is the interior layout, third are the roofs and facades, at last are the structural components. Current buildings often have load-bearing walls which are made up of wet materials such as cement. These are easy to break during demolition and therefore often unfit for reuse, these can be recycled instead.

However, newer buildings should have bindings which are easier to take apart in order to increase reuse. Prefabricated building parts are often designed to be easily installed, and therefore also easily deconstructed. In order to maximize the deconstructivity of a building, the following principles should be followed. First, minimize complexity of buildings. The number of components needs to be kept to a minimum, use lightweight building modules and keep joint connections simple. Second, use materials that are fit for reuse. Third, make use of digital building information such as BIM (Bertino et al., 2021).

Another way of looking at these layers is through the 6S Shearing Layers (6S) model. Which shows that a building does not have a single lifespan (see Figure 5). However, currently buildings are often thought of this way. The 6S model is divided into stuff, space plan, services, structure, skin and site. Stuff defines the interior of a building such as carpets, plants and furniture. The lifetime of these materials is 0 to 5 years. The space plan is how rooms are divided into different usage areas, with a lifetime of 5 to 15 years. Services are the systems such as air-conditioning, energy and water supply which are used within the building. Structure defines the skeleton of the buildings which forms its shape with a lifetime of 80 to 100 years. Skin defines the outside layers on a building such as windows, facades and insulation with a lifetime of 25 to 50 years. Site defines the area which the building is built upon. The area of the building has a lot of impact on the usage of the building. The lifetime of the site is infinite. The 6S model shows that during the design phase, there should be thought in these layers in order to maximize the lifetime of each layer (World Business Council for Sustainable Development, 2020). In table 1, an overview of all barriers mentioned in the literature is presented.

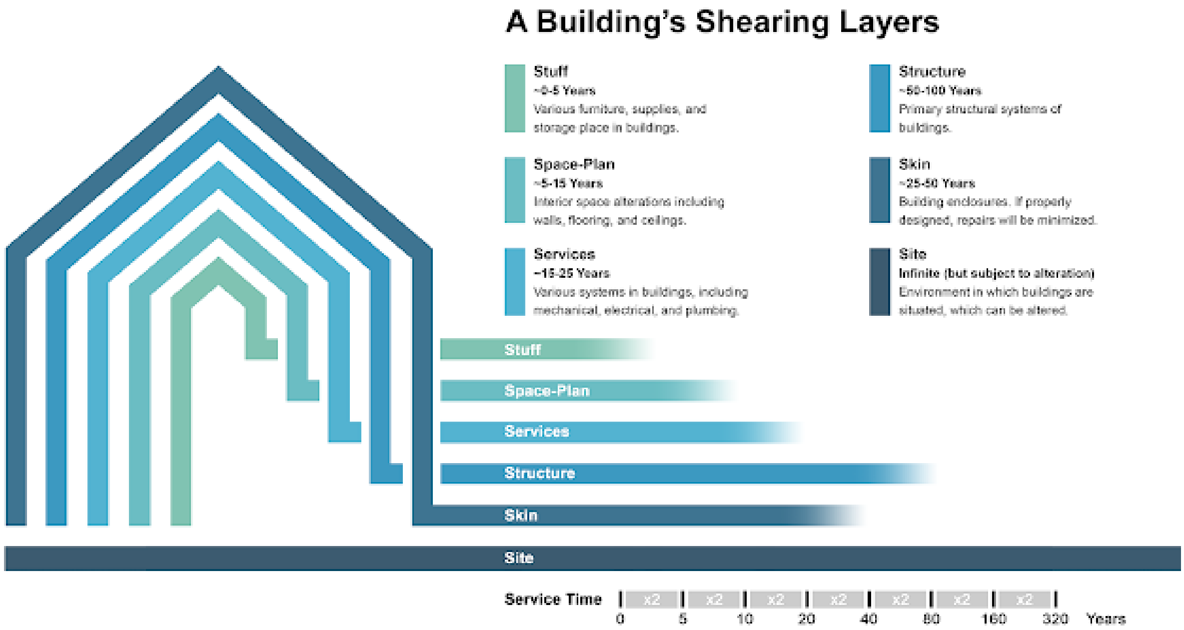

Figure 5, 6S Shearing Layers model (World Business Council for Sustainable Development, 2020)

Table 1, Overview of barriers provided in the literature

Companies are unwilling to change	(Wuni, 2022)
Lack of CE quality management	(Wuni, 2022)
Lack of CE technologies	(Wuni, 2022)
CE is not considered from the start, but more seen as a possibility	(Wuni & Shen, 2021) (Topnes & Sjulstad, 2020)
CE is not found economically viable, nor understood, nor shown	(Topnes & Sjulstad, 2020), (Wuni, 2022), (Adams et al., 2017)
Design stage is not CE focused	(Topnes & Sjulstad, 2020)
No waste management focus in design	(Topnes & Sjulstad, 2020)
Current building block is not CE friendly	(Topnes & Sjulstad, 2020)
Lack of cooperation due to fragmented industry	(Topnes & Sjulstad, 2020)
Lack of digital and physical marketplace for CE materials	(Backe, 2019)
No regulations on requirements for reducing emissions per m2	(Arkitektnytt, 2013)
Lack of partnership culture	(Hosseini et al., 2016)
Buildings are often designed with specific use-case, not flexible	(de Graaf, 2022)
Lack of standardization	(FutureBuilt, 2022)
No focus on end-of-life design	(American Institute of Architects, 2019)
No focus on waste production	(Zero Waste Scotland, 2019)
Lack of focus on selecting CE friendly materials	(FutureBuilt, 2022)
Lack of willingness to design products which can be reused	(Adams et al., 2017)
Reused materials might not be good enough for today's standards	(Miljødirektoratet, 2018)
Lack of end-of-waste regulations	(Adams et al., 2017)
Lack of regulation aimed specifically towards CE	(Adams et al., 2017)
Lack of information on materials in buildings	(FutureBuilt, 2022)
LCA is not used	(Wuni, 2022)
High-start up costs	(Wuni, 2022)
Lack of incentive for contractors to change towards CE	(Wuni, 2022)
Lack of short-term income of CE projects	(Wuni, 2022)
Often cheaper and easier to use virgin materials	(Wuni, 2022)

2.5 Chapter summary

The aim of the presented literature is to use the gathered knowledge to answer the research questions. The literature will provide support to arguments used during the discussions and can be compared to the information gathered during the case study. Knowledge of CE and the construction industry is needed to understand the situation of the interviewees. More in depth-knowledge during the lifecycle stages is needed to understand the CE possibilities offered in the building construction industry.

In the subsequent Chapter, the methodology employed by the study is presented.

3.0 Methodology

3.1 Chapter introduction

This chapter presents how the research was performed and why the methods of research were chosen. The research onion is used to guide the reader through this chapter (see Figure 6) (Saunders et al., 2019).

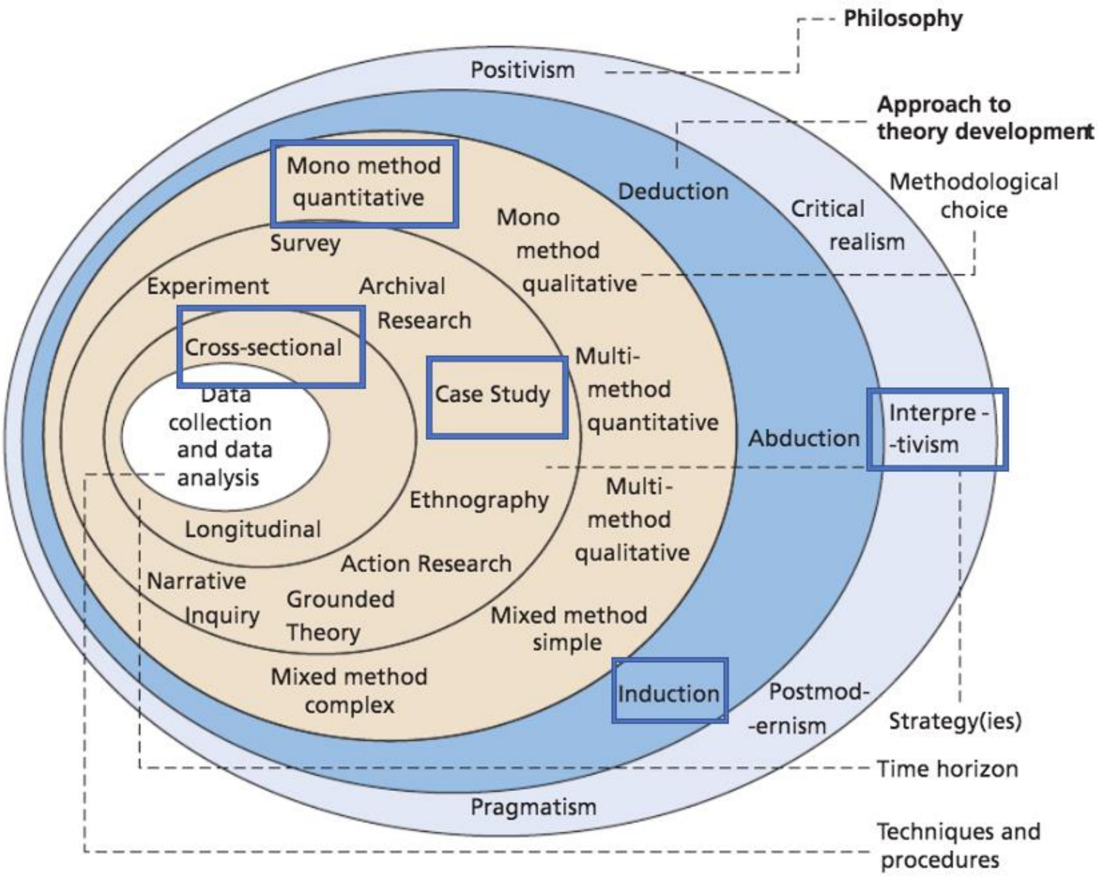

Figure 6, Research onion (Saunders et al., 2019)

3.2 Research Philosophy

Research philosophy refers to a set of beliefs and assumptions regarding the development of research (Saunders et al., 2019). As a researcher conducts their work, they inevitably make assumptions about the world around them. It is essential to reflect on these assumptions before, during, and after the research process, as they can significantly impact the results. These assumptions made by researchers can be divided into three pathways: ontology, epistemology and axiology (Saunders et al., 2019).

Relative ontology focuses on how different people look at a truth. As an example; government support for people without a job. Some people look at this as an important measure taken by the government in order to help people in need while others see this as a waste of money going towards lazy people unwilling to work. Every individual experiences thing from a different light and this influences their choices. In this research, this is relevant for the construction industry and the CE practices. I look upon the construction industry as climate- unfriendly. I might think of CE as an industrial economy not taken advantage of, while giving so many solutions. However, people in the construction industry might look at CE as another method of making the building process more complicated, and other people might look at it as greenwashing. Even though the research is attempted to be as unbiased as possible, there may be some subconscious assumptions which may influence the result of the research.

Epistemology focuses on the different types of knowledge, its validity and relevance to research. It also focuses on how to communicate this knowledge, for example through statistics or through expert opinions. On the other hand, axiology focuses on the impact of a researcher's value on the research process. The researcher needs to consider what the influences of their personal values are on the reason the topic is chosen. The same needs to be done for the method of data collection. In the present study, my personal values have influenced the choice of topic as I have an interest in climate change and think this research can help improve this. The method of data collection as this, is seen as the best way of answering the research questions. The research questions are focused on experiences from the construction industry, which can best be captured by personal interviews, as these can go more in depth.

Following from these assumption pathways, three main research philosophies have been considered in the following part: positivism, interpretivism and pragmatism. Positivism focuses on objective research, meaning no personal viewpoints can be included (Saunders et al., 2019). Interpretivism focuses on people's thoughts and ideas. Through the thoughts and ideas of people the researcher will gather knowledge on the subject (Saunders et al., 2019). Pragmatism is looking at knowledge, not as fixed, but constantly changing. The researcher can change problems to their liking in order to gather new insights (Saunders et al., 2019).

For this research, interpretivism is the logically following choice of research philosophy. In this research, information is gathered through interviews with people working in the construction industry, these interviews give an insight of their knowledge and ideas. Besides, the literature review shows other people's opinions on different subjects. All gathered knowledge is therefore one big collection of ideas and thoughts from all different sorts of people (Saunders et al., 2019).

3.3 Research Approach

The research approach refers to the amount of knowledge the researcher has regarding the theory at the outset of the study (Phair & Warren, 2021). The three approaches used the most often are deductive, abductive and inductive approaches. Deductive is based on testing existing theories by developing hypothesis, often used in the areas of biology and science (Phair & Warren, 2021). Abductive, is when a unique fact is observed and explanation for this unique observation is researched (Phair & Warren, 2021). Inductive, follows a less structured approach in order to find a new explanation of a certain fact. Inductive research often uses small sample sizes and qualitive data (Phair & Warren, 2021).

In this research, an inductive approach is applied. This approach aligns with the main goal of this research, which is to extend the theoretical knowledge of CE practices in the design phase and not to test a hypothesis. A limited number of samples were interviewed in order to obtain qualitative data and answer the research questions. In order to be able to answer the research questions, detailed data was needed. The gathered data from the interviews have given insight into how Norwegian construction companies see the implementation of CE principles in the design phase. In the literature review, a gap has been identified between practical implications and research knowledge on CE. As it is unknown exactly where insight needed to be gathered a structured approach is unfitting (Phair & Warren, 2021).

3.4 Research Strategy and Method

In the research strategy, it is explained how the research is performed. This research is considered as a multiple case study. This is because representatives from different companies are interviewed to gather knowledge. This is a flexible and commonly used method in order to gain a broad insight into a field of knowledge. A single case study is often chosen when a more unique observation is made (Phair & Warren, 2021). However, the implementation of CE practices on the design phase is limited in the whole construction industry, therefore a multiple case study was seen as the best choice.

In a case study, selecting the appropriate cases is crucial. In the present study, a selection of five companies has been made, all these companies belong to the building construction industry. In short, the unit of analysis is the building construction company, while the unit of observation are the company representatives that have different roles in their companies. Qualitative information from these representatives was gathered during the interviews. Qualitative information gives the opportunity for the interviewees to explain what they think is the problem towards a circular construction industry. This gives a broader scope than when limited answers are given in a quantitative method (Phair & Warren, 2021).

Table 2 illustrates the selected cases of the study, their operations, number of employees and the representatives' role in their companies. The actual names of the companies and the interviewees have been anonymized. This has been done so that statements made by companies cannot be traced back to the actual company later in time.

Table 2, Overview of case companies

Company	Company operations	Number of employees	Interviewee function
C1	Consultancy bureau, with focus on all stages of a construction project	5000+	Architect
C2	Company focused on prefabricated construction	20-50	General manager
C3	Project administrative services such as project development and control	20-50	Chief Digital Officer
C4	Construction processes	100-200	Project manager construction
C5	Digital material platform	> 20	CEO

3.4.1 Company 1

Company 1 (hereafter C1) is a consultancy company, which has expertise in a lot of different branches of construction. One of their main expertise is building construction. The company offers consultancy services for every stage of a project from design to end-of-life stages. The company is big and has offices throughout Norway and internationally.

The interviewee is an architect who has been working at the company for over 11 years. As an architect, the interviewee is responsible for the design of new buildings and other construction projects. One of the focus areas of the company is sustainability. However, the fact that they are a consultancy company implies they rely on the budget of their customers and their willingness to become more sustainable.

3.4.2 Company 2

Company 2 (C2) is a company that produces prefabricated buildings and building parts from wooden materials. The company is relatively young and has mostly had individuals, with smaller projects, as customers. In recent years, bigger buildings and companies have been making use of their products. Company B promotes their products with the fact that it is easy to install and takes less time on the construction site. Besides this, a focus is put on sustainability by only using wood. The interviewee is the general manager of the company and an overseer of the production processes and customer contact.

3.4.3 Company 3

Company 3 (C3) is a company which takes over the role of the building owner up to a certain degree. This can be anything from giving advice on a building design to complete project management. The company has a big focus on sustainability circular practices. One of their services offered how to develop a green strategy included with a plan for reuse of materials. The interviewee is Chief Digital Officer, the interviewee has a lot of knowledge on the digital side of construction like BIM and upcoming techniques such as artificial intelligence (AI).

3.4.4 Company 4

Company 5 (C5) is a construction company, which offers services from the design to demolition stage, however, they do not design themselves, they hire an architect. Thus, they have a lot of influence on the choices taken during the construction, less on the design of the building. They also function as a project manager and contract suppliers and other companies in order to fulfil the construction of a project. The interviewee works as a project manager and is responsible for having an overview during the construction of a project.

3.4.5 Company 5

Company 5 (C5) is a company without any physical construction services. It is a platform which can be used by all kinds of companies within the construction industry. Users of the platform can upload a BIM of a building and create a material passport. This way a digital overview of all materials is created, creating a path towards a more circular construction. Furthermore, the platform functions as a marketplace for used materials. The interviewee is the CEO of the company and has a lot of contact with customers especially in finding out what they want from the platform.

3.5 Time Horizons

The time horizon of this study is cross-sectional. All data is collected around the same time period giving an overview of the knowledge at this point of time, there is no focus on the knowledge development over longer time. The study was performed in a limited amount of time, starting from January 2023 and ending in May 2023.

3.6 Data Collection and Analysis

To answer the study's research questions in the best possible way, two approaches (literature review and interviews) were found to be relevant and these are described in the subsequent section.

3.6.1 Interviews

The held interviews are a key part of this research and needed therefore to be prepared thoroughly. The first step was finding people from the construction companies who were willing to do an interview with me. This turned out to be easier than I anticipated. I sent out emails explaining about my research and asking if they might be interested in helping me in this research by answering questions in an interview. I got a response rate of approximately 50%, and those who responded were willing to cooperate. Due to the willingness of the participants, I was able to interview different companies with different functions in the construction industry. Due to this, CE practices were considered from different points of view, resulting in a wider overview of the construction industry and its CE practices.

Following guidelines from Büchele & Schober (2021), I was able to develop an interview guide based on the circular life cycle stages of the construction industry (see Appendix 1). This interview guide was sent to the companies in advance to prepare them, this saved a lot of time during the interviews. The focus of the interview guide was to go through every stage of the lifecycle and see how design methods could have an influence on each stage to become more circular. Besides, I asked what the barriers were based on their given answers and how realistic they thought it was that their answers would become a standard practice. This way, all the research questions were answered while at the same time getting an in depth understanding of their point of view towards CE. During the interview, I asked many sub-questions like 'how' and 'why' in order to get a deeper understanding.

In total, 5 interviews were conducted. Three of the interviews were conducted via Teams due to long travel distances. Two of the interviews were held in person. This was preferable because I was able to get more of a feeling for the size of the company and its work ethics. My role as an interviewer was a bit different per interviewee. Some of the interviewees had a lot of knowledge on CE while others had less, and as such they needed some guidance from time to time. The interviewees' standpoint against CE was also interesting. As some saw it as a solution for the future, while others saw it as an idea which was easy to talk about but difficult to implement. All interviewees were very willing to talk and share their points of view and experiences which was very helpful.

All the interviews were audio recorded with consent of the interviewees. This was done in order to have a maximum focus on the interview process, being able to add in depth questions when relevant. For the transcription process, the most important statements by the interviewees were captured and written down. As the interviews were held in Norwegian, direct citation is not possible and instead, the citations have been translated in such a way that they are as close to the original statement as possible.

3.6.2 Literature review

For this research, the literature review is used to find background information on the building construction industry, circular economy and the combination of both. The literature review was carried out in order to find out whether there were any similarities, differences or other notable observations in comparison to the answers given by the interviewees. The comparison of knowledge gained from the literature and from the case study offers a discussion, where new knowledge can be derived from.

The literature collected is obtained from all different kinds of sources such as research articles, books, reports, websites from governments and companies and newspaper articles. All of the research articles and books were found through the database offered by Molde University College. Through the university's database, several other databases were accessed. The most used database was the ScienceDirect database. In order to get a general understanding of the construction industry and CE, more general terms as shown in figure 7 were used. After general knowledge was collected, the research focused more on CE design in the building construction industry.

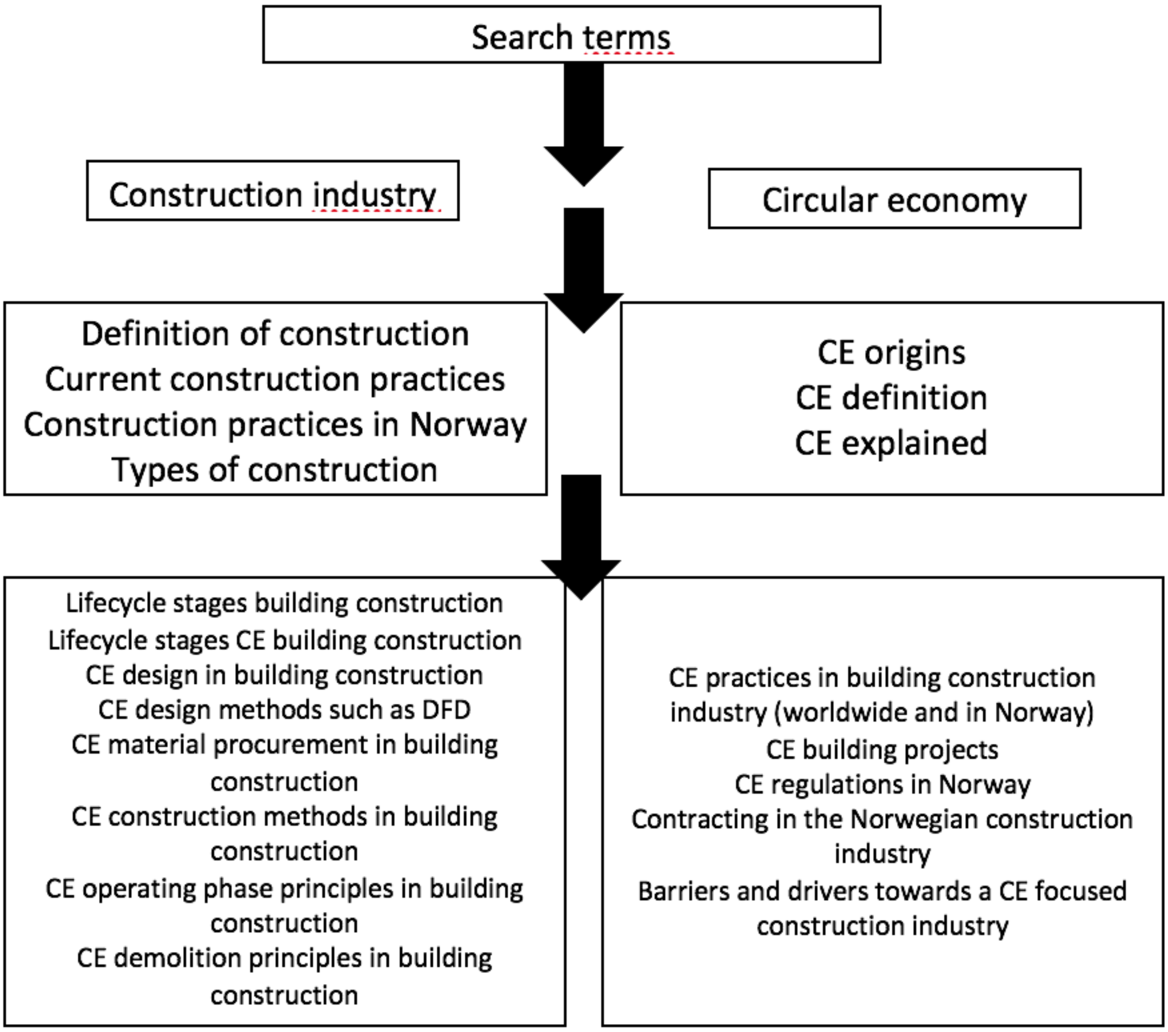

Figure 7, Search methods (own illustration)

3.6.3 Data analysis

In order to analyze the data, the most important statements made were shortened in order to keep the value of the statement but with less words. The overlapping statements were combined and made part of 'groups', creating an overview of relevant statements made and how often they were stated. For each statement made, more in-depth information was gathered from all the interviews. Opinions from different interviewees were compared to see where they agreed and disagreed. How these statements influenced each other was also looked upon in order to look for relations between the different statements.

To reflect and discuss if this research measures and observes what it aims for, and if the collected data can be trusted, validity measures were described, which is presented next.

3.7 Validity

Validity focuses on how objective the gathered information is and whether it is verifiable . Pathirage et al. (2005) state three different forms of validity: internal, external and construct validity.

Internal validity concerns the ability to draw causal relationships from research findings. To ensure that the findings of the present study can be compared, all interviewees were in managerial positions and therefore have similar experiences. Furthermore, all the interviewees have experiences in project management, and know what kind of decisions are made at this level in the construction industry.

External validity refers to the extent to which the findings of a study can be generalized to be used in cases, outside of this context (Saunders et al., 2019). It is difficult to know for sure whether this gained knowledge can be directly transferred. However, CE implementation has been a struggle in multiple sectors. The learnings from the construction industry could be transferred to another industry. However, his industry, just like other industries, has its own individual challenges and can therefore not be copied directly.

Construct validity refers to the measures taken in the research and whether they measure the right phenomenon. In qualitative research, the potential for researcher's bias is a concern. In the present study, the questions asked during the interviews were based on the lifecycle stages of the construction industry by Büchele & Schober (2021), thus increasing the chance of asking relevant questions. Besides, I have no personal interest in the well-being of the interviewed companies. One bias I am aware of is the fact that I see CE as a solution towards a better climate. The criticism of both the literature and the interviewees helps me stay realistic. Additionally, the thesis has been reviewed by a supervisor. This serves as a second opinion able to give feedback when a bias is apparent.

3.8 Chapter summary

This chapter has presented the method of research for this study in order to show the study is credible. This has been done going through all the steps of the research onion. In the subsequent chapter, the study's findings are presented.

4.0 Findings

4.1 Chapter introduction

In this chapter, the results from the interviews held are presented. This is divided into separate parts focusing on the individual research questions. The companies are divided as represented in table 2. For example, Company 1 is shortened to C1, this is done for all the companies.

4.2 CE practices that can be implemented in the design phase of the construction of buildings

This section aims to answer the first research question; *What CE practices can be implemented in the design phase of the construction of buildings?*

None of the companies currently have a clear circular focus in their design methods. When talking about CE, it is looked upon as mostly just reusing materials. Further questions show that energy efficiency is a more standard matter. Prefabrication as a construction method is also already well established. End of life thinking and reusing parts of older buildings has been applied in some pilot projects with varying success. A lot of barriers are mentioned towards the reuse of materials coming from old buildings. C1 mentions that design for flexibility is the way to go towards a circular building construction industry.

> *The design needs to be flexible; it needs to be constructed in a way that it is easy to change its use case. This should be done by using materials which are easy to reuse – C1*

With flexible design, the interviewee focused on the internal design. Rooms and interior decoration need to be designed so that they can easily be reused, either in another or the same building. Keeping the materials in the same building would be the easiest. The interior needs to be adaptable to the wishes of different types of customers. As an example, the interviewee talks about shops.

> *"Shops in a shopping center get replaced quite often, it should be possible to just reuse the same materials over again" – C1*

When picking materials fit for reuse, architects should focus on its reusability. Both during the building lifetime but also for deconstruction. To emphasize this, C1 mentions;

> *"Should we be using concrete? Concrete is reusable, but it takes a lot of input, and it is certainly not easy" – C1*

Although not mentioned specifically when talking about CE, the interviewee did mention the following sustainable focus parts: focus on energy efficiency, considering public transport when deciding where to build, making use of donor buildings and restoring buildings.

Energy efficiency is seen as a part which is more developed than reuse of materials. In the design phase, solar panels or other renewable energy solutions are often considered. However, between the design phase and the construction phase, renewable energy solutions are often taken out, costs or technical infeasibility are usually the cause. Energy efficiency is an important part of the BREEAM guidelines. BREEAM gets used to accomplish a greater matter of sustainability. The location is another aspect which C1 labels as a focus point.

> *"Trying to build close to a train station in order to reduce solo transport gives plus points for the BREEAM certification" – C1*

C1 mentions that the company also has some projects where donor buildings were used. Meaning that one building's old materials were used in the construction of a new building. However, C1 mentions that this is a complex process which costs extra time and money. C3 explained about a similar project where one building functioned as a donor for the other. C3 said that both companies were willing to work on it because both companies earned money from it.

Restoring buildings instead of demolishing and building new is also becoming increasingly more popular.

> *"Three years ago, the company as a whole almost never had restoring projects, now I have three of these projects myself" – C1*

C4 on the other hand has a bigger focus on deconstruction.

"It is extremely difficult to reuse materials coming from buildings these days because they are not designed to be reused. That's why we need to make sure the buildings we make today do have that possibility" – C4

C4 thinks it is a waste of time and money to focus on reusing the current building stock. The current building stock is not designed to be reused and trying to reuse it will cost more than is gained from it. However, C4 does think reuse is the way to go. In order to stimulate reuse, buildings need to be designed in a way which facilitates reuse of materials. Designers need to focus on using materials which have a long lifetime and are easy to reuse. Further, buildings need to be constructed in ways that it is easy to take them apart and put back together again. Standard materials and sizes need to be used, and governments should put up stricter demands for reuse of materials.

C3 emphasizes the bigger focus towards standardization.

"This door right here cannot be reused anywhere else because it is 10 cm too high and 2 cm too wide. It is simply too unique" -C3

The quote by CE shown above is quite simple but elaborates the problem well. When products and materials are all coming in different sizes, it will be a challenge to reuse these. Therefore, C3 hammers on the importance of standardized design. This design needs to make use of products and materials which are formed in standard sizes. When these standard sizes are used in practice, the reuse of materials and products will become easier. C4 also mentions the importance of creating visibility in buildings.

"Currently when reusing materials from a building, you have to start by getting an overview of all materials inside that building, this is quite the process. This overview of materials needs to be a standard way of working when constructing a building. Otherwise, reusing materials will not become an easy process" – C3

C3 points towards the use of programs which create a digital overview of the materials inside the building, a so-called material passport. Here, C3 mentions projects such as Cirpass, funded by the European Commission (Cirpass, 2023) and companies like C5, who offer digital platforms to show material data from buildings. C5 emphasizes this focus towards visibility of buildings.

"How can you reuse the materials of a building when you don't even know what is in it?" – C5

By using a platform such as C5 offers, architects can design buildings while maximizing the reuse of materials and use of sustainable materials. Besides, the platform can be used to create an overview of materials used in buildings. This can be done with new buildings by uploading a file of the design or with old buildings, by for example using 3D-scanners.

C2 did not have a big focus on CE practices in the design phase. The company merely produces and does not work with designing. However, the importance of prices was mentioned.

"Sustainability looks good on paper, but it has no weight against the price" – C2

C2 mentioned this because their customers do not come to them based on how sustainable their products are. Their customers come to them because they do good work for a low price. Where the company can involve some sustainability, it will, however costs is the biggest driver behind decisions.

C3, also, places an emphasis on the importance of the customer wishes.

"Sustainability is considered in the design, however we are 10 out of 10 cases controlled by the customer's wishes, if the customer is not interested in sustainability, it is end of story" – C3

All of the interviewees mention the importance of BREEAM in the design phase. As mentioned earlier, energy efficiency and location are some of the parts considered in the BREEAM certification. A higher BREEAM score also makes a building more attractive and thus easier to sell. The use of BREAAM by all companies shows the impact a framework of government guidelines can make. C4 mentions the following

"BREEAM is only relevant when it isn't expensive" – C4

This statement shows again the importance of cost as a main decision driver. It shows that the design is not considered with a BREEAM point of view. BREEAM is used there, where it fits in well without maximizing costs.

In short, the following circular design methods were mentioned. Design for flexibility, which focuses on constructing buildings in a way that it can adapt to future use cases. Design for deconstruction, which focuses on ensuring that materials can be reused after the building is deconstructed. Design for standardization, which focuses on standard sizing on materials and products in order to enhance reusability.

4.3 How CE practices can be implemented in the design phase of the construction of buildings

This part of the findings addresses the second research question; *How can CE practices be implemented in the design phase of the construction of buildings?* This question is answered based on the results from the first research question.

For example, C1 reveals that almost all materials can be reused if one is aware of it and tries to actively look for ways to reuse them,

> *"My experience with reusing materials in a design is that it takes a lot more time. There are things I don't know and habits that need to change which take time. What I found especially challenging is that I don't know the properties of these materials. Instead of making a choice from raw materials which I know thorough, I have to pick a material I don't know as well. Meaning I have to double check whether it fits there I want it etc. This takes time during the first couple of projects but will eventually be standard knowledge" – C1*

C1 also mentioned that you have to make use of old connection joints and products in different sizes. This makes it more complicated to add these products together. This is why C3 and C4 proposed that standard sizes and materials should be introduced. This will make it easier for architects to reuse products.

Furthermore, C1 mentions that, in order to design for flexibility or deconstruction, architects need to rethink how they design a building. Experience in circular design will need to be gained through trial and error. In order to gain this experience, C3 proposes that the government organizes circular building projects, which private companies can apply for.

This way, private companies can develop their CE knowledge in practice and maybe even develop a specialty, with lower risk.

> *Almost all materials can be reused if you are aware of it and try to actively look for ways to reuse them – C1*

C1 also mentions the importance of a circular materials market.

> *"It is impossible to design or build in a circular manner when there are no circular materials available" – C1*

This materials market needs to be in both physical and digital form. An architect needs to be able to design in a program with direct access to this online market. This way, architects can design buildings making use of the materials that are available at that time. However, in order to create a building design which is CE focused, multiple actors need to be involved. This is of importance as CE design needs proper supply chain collaboration. C1 mentions the additional benefits it could have by including early, involvement of suppliers and demolition companies in the design phase.

> *"Suppliers know basically everything about their materials. I think it would be of great help for me, as an architect, to receive input on which materials to use to create a more sustainable design" – C1*

Suppliers could bring additional knowledge on materials and support the architect in choosing the material best fit for a certain building. Demolition companies could help in making decisions focused on the reuse of materials. Construction forms, and type of materials can be considered as helpful or unhelpful in the process of deconstruction. A construction company could also be a part of the design phase. The construction company can assist in picking a construction method which the architect can focus its design on. This way a sustainable construction method can be used.

Further, some companies explain how they consider the method of construction during the design phase,

> *"Our prefabricated production process almost has a zero percent waste generation for wood materials" – C2.*

This shows that the method of construction chosen has an impact on the total sustainability of a building project. However, none of the companies mention that they consider the method of construction during the design phase. When this happens, this is because it is a specific requirement from the customer. Prefabrication is, although not considered in the design phase, gaining a lot of popularity. The lower costs and energy savings are the main driver for this.

C3 told during the interview that it recently was involved in a circular building project. One building which was ready for demolition was used as a donor for another building, ready to be constructed. C3 mentions the reason for this success was that both companies gained economic profit from it. One company sold their materials which otherwise had been thrown away, the other company was able to buy cheaper materials. Another reason for this success was the match between supply and demand. As C1 mentioned before, its crucial to have a market so that supply and demand can be matched.

C4 mentions that there were times when the company had a lot of second-hand materials in stock but struggled to find an architect willing to work with these materials. This refers again to the lack of CE knowledge and experience stated by C1. This experience will need to be gained by doing low-risk CE projects, as proposed by C4.

> *"We try to reuse materials as often as possible, however the price is decisive. If it costs more than we gain from it, we do not go through with it" – C4*

This statement made by C4 is resonating among all the companies interviewed. In order to start with CE practices, profit needs to be gained from the CE practices. This means that circular design success depends on the economic success. Therefore, economic incentive is something which needs to be achieved when deploying CE practices.

Further, C4 explains how customers need to change their mindset towards sustainable construction. It cannot be expected that a sustainable building will cost just as much as a more standard building. This point of view makes it hard to use CE in practice.

> *"It is not possible to construct a sustainable building for the same price as a normal building" – C4*

C5 also finds that companies are sceptic against building for reuse and reusing secondhand materials. In order to gain economic incentive, companies need to have the guarantee that their old products can be used again. A proper supply and demand market will not be created if suppliers do not have the guarantee that they are able to sell their products.

> *"Every 20 years quite some new regulations have been added to the use of materials. Even, when people want to design for reuse, there is no point in it, because the rules will have changed anyway. In the end, the new rules will not allow the reuse of most of the old materials" – C5*

In order to create a market as mentioned by other interviewees, the platform offered by C5 can be used. The platform offers the possibility for buildings to show which materials they are made of. This can be used in several ways; first, as an overview for the building owner to see what materials are available and can be reused. Second, for outsiders to see if a building could function as a donor. This platform can be used as a digital market for materials coming from buildings.

C5 also mentions the importance of having a national circularity metric, which can measure how circular a building is. This way circularity can be measured, improved upon and possibly used as a selling point.

In short, designers need to rethink in order to properly execute circular design practices. A digital and physical market should be created so that the supply and demand of circular materials can be matched. Supply chain collaborations are necessary in order to successfully implement CE design practices. An incentive, for example profit, has to be created so that companies are willing to go through with CE practices.

4.4 Obstacles which might interfere with the implementation of CE practices in the design phase

This section presents the findings related to the third research question; *Which obstacles might interfere with the implementation of CE practices in the design phase?*

The first barrier mentioned by C1 is the challenge of designing in a Circular manner. This requires architects to think in different ways than they are used to. Design for deconstruction, flexibility and standardization all have their own rules and guidelines which need to be followed. It will take more time, and thus money for these architects to create a design following these guidelines, as it is not yet standard practice. Moreover, the reuse of materials requires knowledge which architects might not have.

C1 mentioned lack of knowledge on CE design as a barrier that might hinder them from implementing CE practices in the design phase,

> *Old materials have different properties compared to new materials, which therefore, again require extra thinking to incorporate these into the design. Old materials might also have old connection joints and all sorts of sizes. The same problem of incorporation appears for old connection joints and materials in all sorts of sizes – C1.*

As previously mentioned, C1 stated the additional value that suppliers could bring to the design stage, if they were included early. However, one of the barriers, mentioned by C1, C2 and C3, is the lack of incentive for the suppliers to change. Materials and products are chosen based on price and not based on sustainability or CE. If reusable materials were to become the standard, this would mean less income for suppliers. Currently, suppliers have no incentive to change their way of doing business as this will generate less income for them. C3 emphasizes the importance of this barrier by stating,

> *"All parts of the supply chain need to have a CE-oriented mindset, otherwise it will not work. Suppliers, for example, should change towards a PaaS business model" - C3*

Even if a supplier is supplying reused materials, there are still several challenges. For example, there are regulations on materials which often are changed. As mentioned by C2 and C4,

> *If you were to let a building stand for 20 years and then want to reuse its materials, it is possible this will not be allowed by then – C2*

This is a barrier because companies that are willing to design for deconstruction and thus wanting to reuse materials are not sure if they can actually reuse these materials. This lack of assurance that materials can be reused gets companies to not invest in CE practices.

Further, C1, C3, C4 and C5 mention the challenge of who gives guarantees for the use of second-hand materials. C4 emphasizes this by stating,

> *"Who is going to give a 20-year guarantee on a product which already has been used for 20 years, and who is going to accept a product without any guarantee?" – C4*

Often suppliers do not want to give guarantees and building owners will not accept this. This is because the materials are not designed to be used multiple times. This again refers back to the previous barrier of not having assurance to design materials lasting multiple lifetimes.

Another barrier, mentioned by C4, is the fact that people want new houses, meaning reused materials are less popular. Building owners want to sell or rent out their buildings, so they will build according to the wishes of their customer group. Furthermore, C4 mentioned that there is currently a challenge of finding an architect who can and is willing to design using reused materials. This can be traced back to the barrier of lack of CE knowledge mentioned before by C1.

C3, C4 and C5 mention that it is hard to reuse materials from old buildings as it often is unknown what exactly the building is constructed from. The process of creating an overview individually for every building is time- and cost consuming and is also a barrier for reusing materials. Another barrier is mentioned by C3 and C4, here are no standard material- and product sizes used, which gives an extra challenge when trying to reuse materials.

Another barrier mentioned by all interviewees, is the power the building owner has during the entire construction phase. At first, the owner needs to make a priority out of using CE-principles. If there is no interest or budget for this, it will not be considered in the design phase. C1 emphasizes this by stating

> *"It doesn't matter how many sustainable design ideas I have had for the last couple of years, if the client doesn't want it its's of no use" – C1*

One of the barriers mentioned by C1 is the long return on investment time for CE practices. Bigger investments require bigger upfront budgets, which are not always available. C3 emphasizes this by saying that,

> *"Cashflow needs to be generated continuously. If a project cost so much but does not generate profit until later, it is an unattractive investment".*

However, C3 mentions another barrier opposed to this: the importance of initial investment analysis. The initial investment is considered as the decisive factor when starting a project. There is a lack of use of LCC calculations. LCC calculations look at the cost during the complete lifecycle of a building and will thus create a better overview for CE investments.

C3 mentions that one of the reasons the LCC costing is underused is because it is also underdeveloped for the construction industry. Exact costs, profits and return on investment times are unknown for CE practices. This gives insecurity when considering CE practices as a long-term investment.

Besides this, C1 mentions that owners often change demands during the construction phase, hence making it hard to implement CE principles. As CE practices require long-term visions and investments, short-term changes will intervene with these long-term visions and therefore reduce CE potential. Further, C4 explains that when short-term changes are made or cost-cuts are needed, CE practices are often first to be abolished. As CE practices are not a requirement but merely a bonus with high costs, these are considered as less important and thus thrown out.

Barriers mentioned by several interviewees are the lack of CE specific regulations. In order to create a CE focused building industry, some of the interviewees want stricter regulations. C4 and C5 mentioned the need for regulations focusing on a demanded reuse percentage per building. C1 and C3 on the other hand were happy with the current state of regulations, as they think it could be too pressing to implement such rules at this point.

In table 3 below, an overview of the barriers provided during the interviews is shown.

Table 3, Overview of barriers provided during interviews

Barrier	CE design is more complicated	Suppliers lack incentive to change	Challenges when reusing materials	Power of building owner	Costs
Causes	Lack of knowledge CE design	Buyers pick materials based on price	Changing regulations	Owner decides how much CE will be in building design	CE principles are first to go due to high costs and difficulty
	Old non CE friendly habits	Less sales with reuse of materials	Hard to give or accept guarantees	Owner changes demands during construction impacting CE	Initial analysis more important than LCA
			People want to have new products		LCA is underdeveloped
			Hard to find architect willing to design with CE		
			Lack of material information from buildings		
			Lack of standard sizes		

4.5 How to overcome the identified obstacles

This section aims to answer the fourth research question; *"How can the obstacles, which interfere with the implementation of CE practices in the design phase of buildings, be overcome"?*

The first barrier mentioned is the lack of knowledge on circular design. In order to overcome this obstacle C3 and C4 mention the need for more funds towards research and pilot projects focused on CE. Funds should go towards pilot projects setting up infrastructure for a CE focused construction industry.

> *Funds are needed because the industry is too fragmented and will move too slow out of itself – C3 and C4*

The industry will learn by trial-and error principles, that is, finding out the best way to overcome such a barrier by trying out one or more ways and eliminating causes of failure.

For example, one way could be for the government to open circular pilot cases, where the construction industry can apply for. These should be smaller, low risk projects focused on CE as a way for the construction industry to learn. Currently, Statsbygg, the state-owned construction management company, has several big CE-based projects (Rødningen, 2022). The rest of the construction industry is getting less opportunities. These big Statsbygg projects should be divided into smaller projects available for the whole construction industry.

In order to make it easier to design with reused materials, the barriers of lack of standardization and lack of supply and demand market need to be solved. C3 mentions that,

> *"…the issue of standardization needs to be solved by the government. Regulations need to be put in place creating a system of standard sizes" - C3.*

In order to start creating a marketplace for reusable materials, an overview of materials available in the current building stock needs to be created. C3 mentions the need of a material passport, which can be created with initiatives such as the platform offered by C5.

> *"Our platform offers the possibility to get an overview of the environmental impact each material makes, making it easier to choose more sustainable materials" – C5*

When an overview of the materials in the current building stock is provided, the start of a CE market is shown. As a digital supply is provided via the overview in the current building stock, architects can start to consider these materials in their design. This means that the demand is also starting to pick up. As these architects then design with 'design for deconstruction' principles, new supply is automatically created. However, the barriers changing regulations and how to give and accept guarantees on older materials is not yet tackled. These two barriers cause insecurity when trying to reuse materials.

In order to get suppliers to become more aware of CE, C1 mentions that suppliers should closely collaborate with the architect. This way the architect and the supplier can look for ways to reuse materials, which can pave the way towards circular business models such as PaaS and Buy-Back principles. The suppliers also have extra product knowledge which will improve the design and its circularity.

Further, C4 mentions the importance of offering both new and reused products where the buyer can choose which one to choose.

In my home country, I can use the same material, either new or second-hand – C4

Although these solutions would help out the architect and the circularity of a product, there is still no incentive for suppliers to actually change this way. Chances are that closer collaboration will cost the suppliers more time and thus money, making it unattractive to join this process.

One of the most important barriers mentioned is the power of the building owner. The building owner decides whether to invest in CE or not. C3, C4 and C5 mention the need for strict regulations on CE. The government needs to demand that a certain percentage of a building's materials is used again when deconstructed. This way, the whole industry will need to change its mind and start actively thinking about CE. Government funds in the form of rewards when completing a CE goal can support this. The better the CE target achieved is, the higher the reward. This way, building owners will have an incentive to demand CE materials and construction processes. Due to this demand, suppliers, architects and other players in the market will start to change their ways towards more CE oriented.

Building owners will try to stop changing their demands during the construction phase as this impacts the result of the circularity score in a negative way. As CE-initiatives are often long-term investments, LCC calculations will become more important. The knowledge on this will expand by trial and error.

4.6 Chapter summary

This chapter has presented the findings which were found through the interviews held with the case companies. During the interviews, several CE design methods are mentioned, how to implement these, what kind of barriers are met and how these can be overcome. The following chapter discusses the findings while comparing them to the literature and the researcher's personal thoughts.

5.0 Discussion

5.1 Chapter introduction

In this chapter, the study's findings are used as a base to answer the research questions. These findings are weighed up against the findings from the literature shown in chapter 2.

5.2 CE practices that can be implemented in the design phase of the construction of buildings

C1 mentions to design for flexibility in order to be able to easily change the use-case of a building. This is in line with FutureBuilt (2022) and Melton (2022), who advocate for design for adaptability, in which a building's lifespan is extended by making it possible to adapt the space with minimal disruption. FutureBuilt (2022) explains the three main focus areas of design for adaptability: generality, flexibility and elasticity. Generality focuses on easy accessibility of rooms and even daylight distribution. Flexibility focuses on that both interior, walls and its technical systems are easily adjustable. Elasticity focuses on the changeability of rooms and its technical systems when extending either horizontally or vertically (FutureBuilt, 2022).

Furthermore, design for deconstruction is mentioned by C4, where they emphasized that the design phase is critical to maximize reuse of building materials. Adams et al. (2017) mention that this method is the best way to keep reusing materials over a longer period of time. In order to deconstruct the building properly the building layers by Bertino et al. (2021) or the 6S model can be used. These models show how to properly deconstruct a building. Besides this, the models show the lifetime of each layer in order to maximize reuse of each layer.

C3 and C4 also mentioned the design for standardization, as a necessity. Without standardized sizes it will be impossible to reuse materials and products on a big scale. This method is also mentioned by Adams et al. (2017) as a way of reducing the complexity of reusing materials.

The findings also reveal that C2 produces prefabricated building parts which can be easily installed into buildings, a perfect fit for modular design. According to American Institute of

Architects (2019), design for modularity is a method that focuses on designing a building in modules, which can easily be installed, replaced and taken apart. However, C2 merely produces and is not part of the design process. Building owners who use their services do this because of cost savings and reduced construction time, not due to environmental reasons.

From the interviews, it showed that during the design phase, not much focus is put towards reducing waste. It is seen as something which happens during the construction phase and should instead be tackled there. Therefore, it is also logical that C2 and C4, companies who were more directly involved in the construction phase, had a bigger focus on this. C2 has a waste rate close to zero percent for wood materials. In general, C2's production process produces little unused parts. The parts that are unused, are instead used for generating heat, creating a cycle. Asphalt slabs are also used during the production, and here again almost no waste is created due to an efficient production process with use of standard lengths. C4 tries to minimize waste by reusing materials, and even has its own storage for materials which have a possibility of being reused. However, in practice reusing these materials is often a challenge as it is hard acquiring these materials to fit in with the rest of the new materials.

Waste separation is a focus which companies need to have, as regulations have become stricter and require a waste-separation rate of 70%. Besides this, all construction projects which produce more than 10 tons of waste need to separate all waste, create a waste-plan and final waste report (Holm, 2022). Zero Waste Scotland (2019) mentions design out waste as a design method specifically aimed at minimizing waste. Zero Waste Scotland (2019) also mentions the design methods of specifying reclaimed materials and reused materials. Although none of the companies mention this as a specific design method, it is mentioned as an important part by all. Reusing materials is seen as a key aspect of circular economy. However, in practice it shows that this is hard to both design and construct with. Different problems such as changing regulations, guarantees and lack of market structure are mentioned.

C1 mentions the importance of considering energy efficiency when designing a building. Pacheco et al. (2012) mention design for energy efficiency. This is seen as one of the most important improvements as the operating phase produces about 85% of the CO2-footprint during the lifetime of a building (Peng, 2016).

It is essential to make sure that circular design pre-integrates lifespan considerations, and future reuse of materials and structures at every stage of the project (de Graaf, 2022). The key word here is 'every stage of the project'. The circular lifecycle stages of a building construction project have earlier been defined as design, procure, construct, operate and end of life. The problem of the above-mentioned design strategies is the fact that they often focus on a certain goal within one of the lifecycle stages and thus lose efficiency in other stages. As an example, design for adaptability has a strong focus on the operating phase. This strategy ensures the lifetime of a building is extended as long as possible and can be used no matter the wishes of the user. There is, however, no focus on the reuse of materials or the construction method.

Table 4 below shows what the specific focus points are of the different design methods. The design methods often touch multiple stages but have a clear focus on the stages mentioned in the table.

Table 4, Overview of CE design methods

Design method	**Lifecycle stage focus**
Specify Reclaimed and Recycled materials	Procurement
Design for Standardization	Construction
Design for Modularity	Construction
Design out Waste	Construction, End of Life
Design for Energy Efficiency	Operating
Design for Flexibility	Operating
Design for Deconstruction	End of life

To create a design process as described by de Graaf (2022) where there is focus on all stages of the lifecycle, these design methods need to be combined. The design method should become lifecycle oriented. For the procurement phase, focus should be put on acquiring reusable materials. For the construction phase, focus should be put on minimizing construction time and waste by using modular construction. For the operating phase, focus should be put on maximizing the building usability over its lifetime and aiming for green energy production. For the end-of-life stage, focus should be put on maximizing the number of reusable materials and minimizing the produced waste. In order to help all this, standard sizes should be used on materials and products so they can easily be reused. This process is visualized in Figure 8.

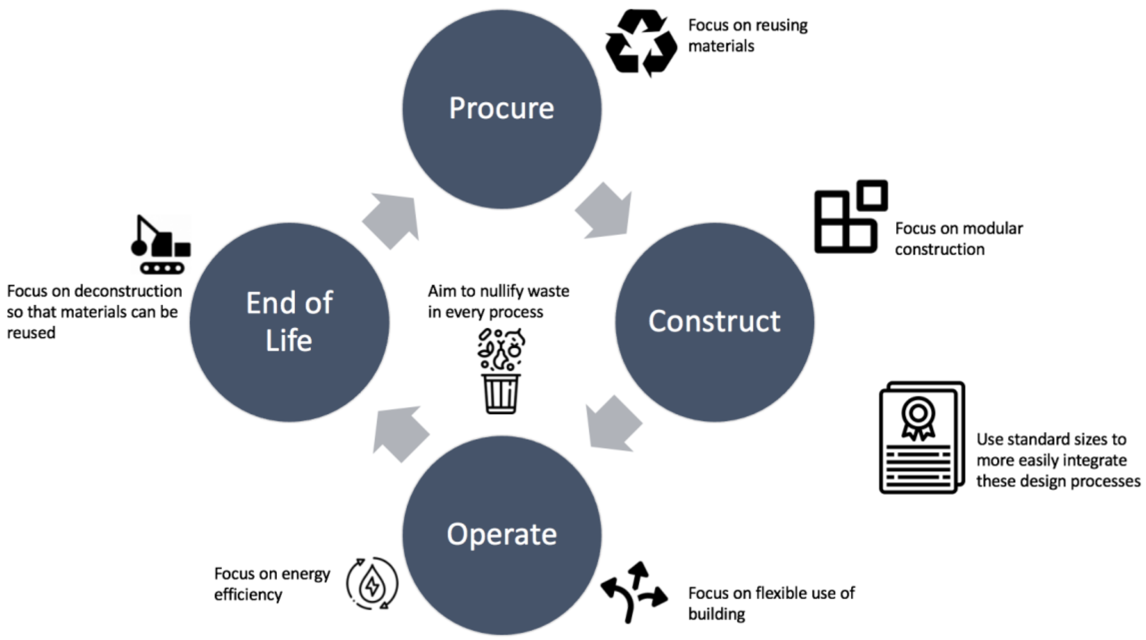

Figure 8, Focus points of CE design in lifecycle stages (own illustration)

5.3 How CE practices can be implemented in the design phase of the construction of buildings

C1 mentions the knowledge gap which needs to be overcome in order to design for a CE. This is in line with the literature which suggest the following. On an organizational level, Wuni & Shen (2021) mention that if companies see CE as a business model instead of a sustainable requirement, more focus will be put towards CE, resulting in a better outcome. To get companies to create a sustainable business model, companies need to change. However, no company will change its business model if it does not guarantee more profit.

There are several methods which can be used to create a push towards CE-oriented business models. The first one, mentioned by C3, is show how CE can be profitable, emphasized by Adams et al. (2017). On a project level, C3 mentions the need for pilot projects. These pilot projects should be arranged by the government, where private companies can apply for these and thus build up CE experience in a low-risk manner. Government funds should be offered so that companies can try CE principles without taking big economic risks. This way CE knowledge is gathered, making the process faster and cheaper next time. Adams et al. (2017) mentions that an information campaign needs to be started. CE needs to be clearly defined and both economic and environmental benefits need to be clearly shown. This way a better understanding is developed and ensures companies will not look at CE as an extra cost but as an opportunity.

The second method mentioned by C4 and C5 considers regulations, focusing on an increase of reuse of materials, this is backed up by Adams et al. (2017) and Arkitektnytt, (2013). The regulations focusing on reuse of materials are as follows: C4 and C5 want strict demands on the number of reused materials from newly designed buildings. Meaning that architects will have to focus on reusing materials already from the design phase on.

On top of this regulation, a maximum limit should be put on materials which emit greenhouse gasses (Adams et al. 2017 and Arkitektnytt 2013). One step further could be to add a minimum requirement for greenhouse gas reducing materials. Adams et al. (2017) mention the importance of end-of-waste regulations. Meaning regulations focusing on the reuse of waste, trying to keep actual waste production close to zero. For building construction, this means that the reuse of building materials needs to be optimized.

The third method has not been mentioned during the interviews but comes from the literature, focusing on environmental costs. This can be done in the form of a CO2-tax as explained by Adams et al. (2017) or in the form of an Environmental Cost Indicator (ECI), explained by Hilege (2019) and de Graaf (2022). A CO2-tax puts a price on CO2 production, companies producing a lot of CO2 will thus have higher costs. This CO2-tax needs to consider CO2-taxes during production of materials and the building itself, building use and demolition of the building.

The ECI is an indicator which puts all environmental costs across the value chain of a product into a single number. Products with a good (low) ECI rating become more attractive to procurers, even when a product is more expensive. Therefore, the ECI gives incentive for producers to create more sustainable products, even when these are more expensive.

The first method might be the one the construction industry prefers the most, as this is the one with the least regulations. However, as stated by several interviewees is that the Norwegian building construction industry is very fragmented. Change will happen quite slowly, and most likely too slow in order to reach climate goals set in the European Green deal by 2050. (Regjeringen.no, 2020)

The other two methods are pushing both the companies and the building owners towards a CE-oriented market. This will thus create incentive to change, both on the demand and supply side. No matter which method is chosen, the important part is that the companies will create more CE-oriented business models making it easier to apply CE principles in the design phase.

The reason a circular business model is so important is because early commitment is key for CE design success Wuni & Shen (2021). If companies start a project by saying we want to reuse this percentage of materials and have an energy production of this amount, the project team will focus on clearing these goals.

It is important that these goals are set in the beginning. The later these goals are introduced the harder it becomes to achieve them. These CE goals need to be setup by the owner; however, all value chain players should be involved in the set-up of these goals. These players, including suppliers, construction and deconstruction companies, engineers and architects all have relevant knowledge which will make it easier to create CE goals. The building owners’ job will be to make sure all players truly aim for their CE goals and ensure cooperation between these players.

It is difficult to ensure cooperation between companies who have different goals. A supplier wants to sell as many materials as possible, a construction company wants to build as much as possible for the lowest costs, they have no interest in whether a building is flexible, adaptable or energy efficient. This will only cost them more time and money. Building owners, on the other hand, want to have the most sustainable and best-looking building for the least amount of money. In order to align these interests, newer forms of contracts can be used.

Several interviewees mentioned the importance of having close collaboration with suppliers and other relevant players during the design phase. Eder (2019) mentions the use of collaboration contracts in order to align interests. These contracts are based on the fact that designers, engineers, construction companies, materials suppliers and product manufacturers are involved as early as possible in the project. It requires strict communication between all actors during the whole project. The contract is built upon mutual trust and openness. This is relevant for all involved actors, both in financial settings and technical solutions.

The involved actors need to have common goals and common financial interests. The financial side of things is arranged through a target price setup together by all actors. The amount of work an actor does towards the target price is how much they get paid; this is decided upfront. By setting up these contracts, companies get paid fairly and at the same time have an incentive to aim for higher degrees of CE.

In short, companies need to have a more CE-oriented business model in order to achieve early commitment. In order to create a CE-oriented design phase all players need to be involved, making use of their knowledge to achieve the best solutions. Economic interest can be aligned through new forms of contracts. After this has been done CE practices as mentioned in chapter 5.2 can be implemented in the design phase. The points discussed above are shown in figure 9 below.

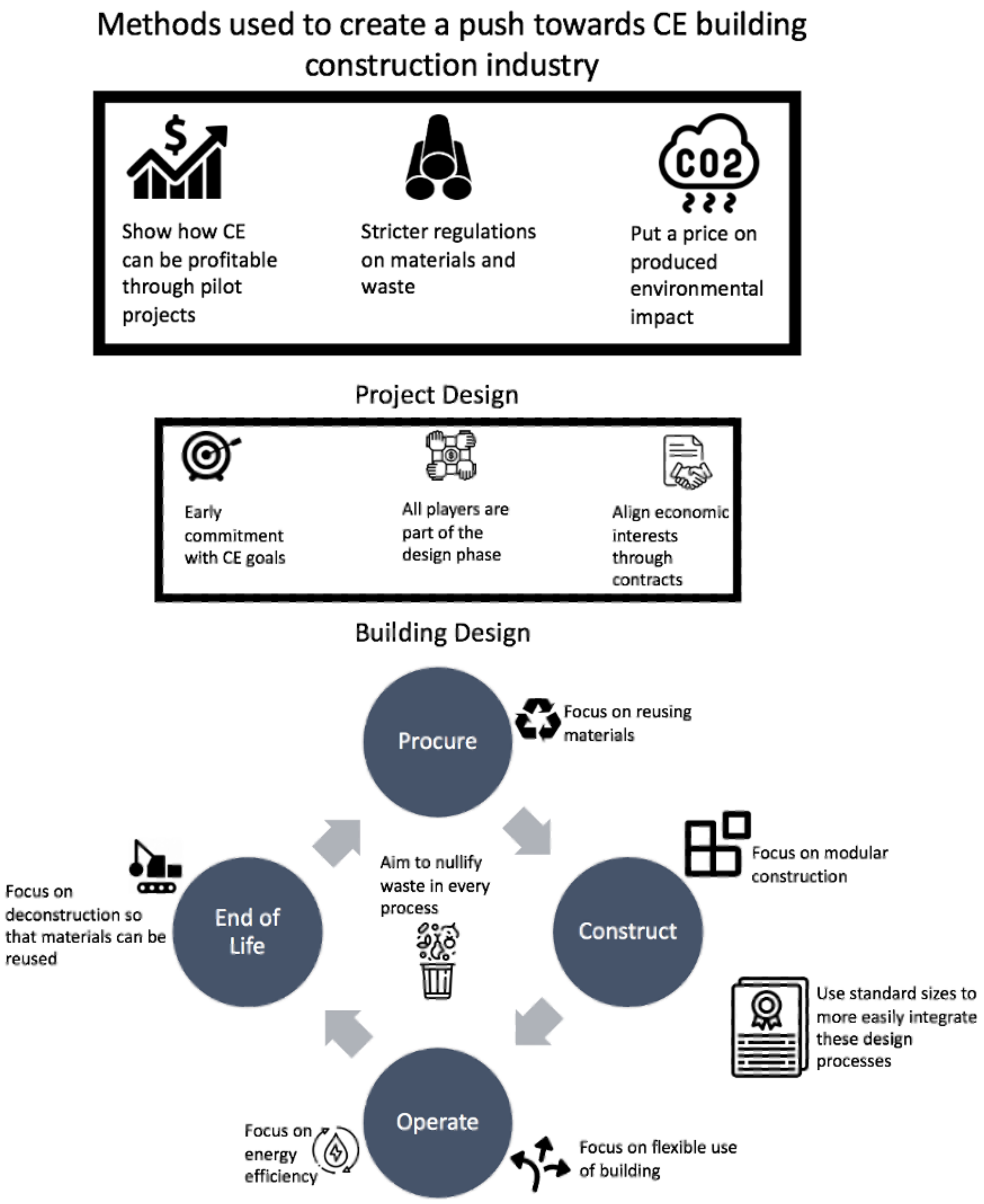

Figure 9, How CE practices can be implemented in the design phase (own illustration)

5.4 Obstacles which might interfere with the implementation of CE practices in the design phase

In this section, an overview of the barriers accumulated in the literature and during the interviews is given. Focus is put on whether barriers are mentioned by only one or two sources or specifically mentioned by multiple.

During the interviews, the need to change habits and ways of thinking was mentioned by several interviewees. A lack of awareness and understanding was seen as a challenge, lack of interest not so much. During the interviews, it became clear that companies were interested in embedding CE principles in their business operations but were struggling due to lack of knowledge, costs and infrastructure. This is emphasized by the literature, where focus is first put on the industry as a whole. Barriers mentioned by Adams et al. (2017) include lack of CE awareness, understanding and interest. CE is seen as another sustainability requirement and not as a solution or business model which can help both the environment and the industry.

Project based, lack of quality CE management is shown, as the case companies had no specific CE frameworks, goals or similar guidelines in order to increase CE. This is emphasized by Wuni (2022), in which the following barriers are mentioned: companies are unwilling to change, lack of CE quality management and lack of CE technologies. CE technologies are in development, C5 is a good example as a platform specifically focused on CE. However, the platform is still in development and was at the time of interviewing still developing options to improve CE. Unwillingness to change got further emphasized during the interviews. The companies need to gain money in order to change the way they do business. It is not that companies are principally unwilling to change, but more that CE has not shown profitable enough for them to change. All of the above barriers can be explained through a lack of incentive to change for the building owner, resulting in a lack of CE commitment.

All interviewees mention the power of the building owner as a decisive factor. If the building owner is not CE oriented, there will be no CE practices. This power the building owner has combined with the lack of incentive to change makes it very easy for building owners to neglect CE principles.

Opinions on whether the regulations in Norway were currently at a right place were divided. C4 and C5 thought the regulations needed to be more pressing and include specific demands for the amount of reuse and energy efficiency a building should have. C3 had a more neutral opinion due to the fragmented state of the construction industry. Due to big differences between companies and their current CE experience, it would be too pressing to have circularity demands implemented now. C3 did however, want more pressing rules over time. C1 was satisfied with the current state of rules and expected these to focus more on CE over time. In the literature, it is shown that there has been quite some development in the Norwegian regulations towards CE in the construction industry. Barriers still mentioned in the literature were no specific regulations towards CE such as: no end-of-waste regulations and no regulations on requirements for CO2 reducing materials (Adams et al., 2017; Arkitektnytt, 2013) .

The fragmented state of the construction industry is also shown through a lack of partnership culture (Hosseini et al., 2016). Although not explicitly mentioned as a barrier, all interviewees did mention the possibility of better collaboration possibilities with other contractors such as suppliers and deconstruction companies.

Another barrier, mentioned both by the interviewees and in the literature, is the current building block is CE unfriendly, as it is not designed to be reused (Topnes & Sjulstad, 2020). Besides this, it is also relatively unknown exactly what is inside the current buildings (FutureBuilt, 2022). C4 sees the reuse of the current building block as a waste of time and money and says focus should be put towards circular design. C3 on the other hand says the current building block is already so big, a solution must simply be found. C5 works on the issue of information gathering on the current building block. Due to the lack of Circular building stock, a proper CE market is also lacking. Both a digital and physical market are needed in order to create a CE market where demand and supply can be matched.

Both C1 and C4 mention the need for more design, focused on deconstruction and flexibility. FutureBuilt (2022) also mentions the lack of standardization as a barrier. Standardization in both use of materials, products and sizes. C3 and C4 emphasize this but focus mainly on sizes and less on types of materials. C1 emphasizes this by stating that it is difficult to design with materials in all sorts and sizes. Design focused barriers mentioned by Topnes & Sjulstad (2020) include lack of CE focus during design stage such as lack of waste management, lack of design for deconstruction and flexibility (de Graaf, 2022; American Institute of Architects, 2019).

C1 states a lack of focus on selecting circular materials as a problem but directs this towards a change of habits and knowledge which will come over time. This is also mentioned as a barrier by FutureBuilt, (2022). Currently, another problem for companies is wanting to try CE design, as architects willing to aim for circular design are hard to find. C3 mentions that suppliers have no incentive to make circular materials. Adams et al. (2017) emphasize this by stating that suppliers are unwilling to design circular materials. Even when circular materials were to be produced, a following barrier is changing regulations, as mentioned by several interviewees.

Regulations change over time and make it difficult to reuse materials and give even less incentive for suppliers to try and design in a circular way (Miljødirektoratet, 2018). Besides this, the costs of virgin materials is often lower than reused materials, making companies unwilling to pick reused materials. Another barrier mentioned by the interviewees is the problem of giving or accepting guarantee on reused materials. Which can be explained by the fact that regulations might change, and materials are not designed to last several lifetimes, making it difficult to give guarantees.

An economic barrier mentioned by Wuni (2022) is high start-up costs for CE projects. These investments are often earned back over time. According to C3, this return on invest often takes too long. Wuni (2022) emphasizes this by mentioning the lack of short-term return on investment (ROI) for contractors, making CE projects unattractive. Beside this, C3 mentions the fact that initial cost analysis are more important than LCC calculations, which is also mentioned by (Wuni, 2022). C3 explains this by saying that LCC calculations in the construction industry are underdeveloped.
All the identified barriers are shown in figure 10, below.

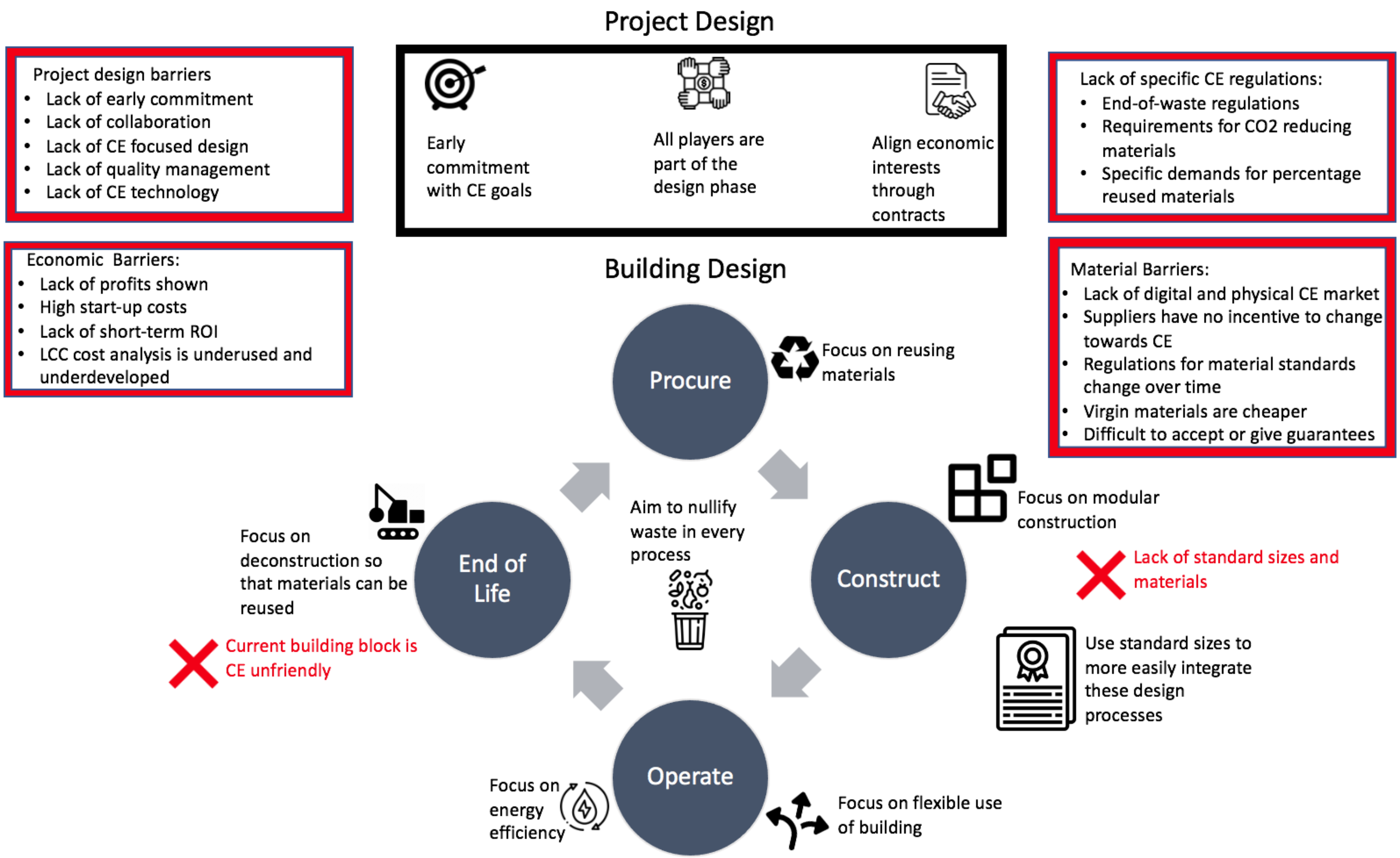

Figure 10, Overview of barriers in design phase (own illustration)

5.5 How such obstacles can be overcome

The first barrier which needs to be overcome is the power of the building owner. This barrier is so crucial because it blocks the way towards all CE practices. If this barrier is not overcome the barriers mentioned below will not be overcome either. In chapter 5.3 several methods were discussed which gave the building owner incentive to change towards a CE oriented design phase. These were the implementation of either regulation focusing on materials and waste, a CO-2 tax or an ECI.

Project design barriers, lack of early commitment and lack of collaboration have also been discussed in chapter 5.3. The companies simply must create sustainable solutions and must therefore commit to these goals early in order to make it a success. Lack of collaboration will be fixed through new forms of contracts. Following this early commitment, CE quality management will be executed. This quality management will ensure the CE results are becoming better. A lack of technologies will be fixed following the need of the market. As CE practices become more mainstream, new technologies will be developed.

CE projects have high start-up costs and lack of short-term ROI for contractors. By making new contract forms and focusing on long term collaboration as mentioned in chapter 5.3, payments can be divided over longer periods of time and ensure lower initial investment costs. Contractors can demand certain upfront costs in order to create the short-term cash flow they need. Another method which could help both reduce the high initial costs as the lack of short-term costs for contractors is PaaS. If contractors turn to a PaaS business model, they will have a constant cash-flow and investors have less initial investment costs. If companies were to have a lack of cash-flow due to long-term sustainable investments a government fund could be set up to help out where necessary. LCC calculations will be developed as they become more important, CE investments are long-term investments and will thus need LCC calculations. Meaning both the quality and the usage amount of LCC calculations will increase (Wuni & Shen, 2021; Eder, 2019)

C1 mentioned the barrier of designing in a Circular manner which is challenging due to lack of knowledge and experience. This experience can be gained through pilot projects as mentioned in chapter 5.3. Through these government-hosted pilot projects experience is gathered, reducing the lack of knowledge. This can be combined with an information campaign as mentioned by Adams et al. (2017) in chapter 5.3.

One of the focus points of CE building design is designing with reused materials. However, in the procurement of reused materials, several barriers occur. There is a lack of both a physical and digital CE market, suppliers have no incentive to change towards CE, regulations for material standards change over time, virgin materials are cheaper and difficult to give or accept guarantees on reused materials.

When an overview of the materials in the current building stock is provided, the start of a CE market is shown. As a digital supply is provided, via a digital passport created from the current building stock, architects can start to consider these materials in their design. This means that the demand is also starting to pick up. As these architects then design with ‘design for deconstruction’ principles, new supply is automatically created.

The incentive for suppliers will come due to the change in the market as shown in chapter 5.3. Building owners want sustainable materials and thus will suppliers have to deliver this. They will change following the market.

Suppliers can also change to a PaaS business model, which is mentioned by several interviewees and by the literature (Adams et al., 2017). An online marketplace needs to be formed which can be used by architects to see what materials are available when designing a building. The platform C5 is working on such a function.

As more second-hand materials become available over time, prices will go down as well. Beside this, regulations like a CO2-tax or ECI will make it more attractive to pay more for sustainable materials. However, a government fund, supporting the procurement of sustainable materials, might be needed in the beginning in order to get the market going.

Unfortunately, companies will pick new sustainable materials over second-hand materials if the government cannot guarantee that these can be reused over time. This is a risk for the companies, which needs to be taken away. The government needs to guarantee the use of these materials or an economic replacement when regulations considering the reuse of materials make their invested materials unusable. For instance, as already noted, guarantees are hard to give when materials are being reused. However, when the government gives the reassurance that materials can be reused over longer periods of time, companies will invest in materials and methods to extend the lifetime of materials. Then this reassurance is easier to give and accept, as both companies know the material is designed to last long. These materials will also need to be designed fitting inside a system of standardization. This system should be created by the government.

The opinions on whether more CE-oriented regulations should be implemented were divided as explained in chapter 5.4. Regulations are only needed if the market is not moving into a sustainable direction out of itself. However, in chapter 5.3, several methods to get the market to move in this direction were discussed. The use of CE-regulations was one of these, thus regulations could be implemented but are not necessary if one of the other methods are chosen. A combination of the several methods is also an option to get the market to aim for more sustainability.

Next, the study's conclusion is presented.

6.0 Conclusions

6.1 Chapter introduction

This chapter gives an overview of the research conducted. It sums up the findings and discussion, explains both theoretical and managerial implications, limitations of the study as well as suggestions for further research.

6.2 Research summary

This research is a multiple case study within the Norwegian construction building industry. The objective of the study was to find out which CE practices can be used in the design phase, how these CE practices can be implemented, which obstacles might interfere with their implementation and how these obstacles can be overcome.

The first research question is as follows: "*what CE practices can be implemented in the design phase of the construction of buildings?"* During the interviews, design for deconstruction, design for flexibility and design for standardization were considered as the most important CE practices as far as the design phase is concerned. From the literature the design out waste, design for energy efficiency, design for modularity and specify reclaimed materials were added to these. Focus should be put on every aspect of the lifecycle stage, where the perks of these design methods should be used to maximize CE in each lifecycle stage. This means trying to procure CE materials, constructing in a modular way, ensuring the building is use-case flexible, energy efficient and can be deconstructed at the end of its lifetime minimizing the total waste creation.

The second research question is*: "how can CE practices be implemented in the design phase of the construction of buildings?"* In order to implement these principles, it is necessary that companies get a more CE-focused business model. This can be done by pushing the industry in a CE direction, either by showing how profit can be made using CE practices or by implementing regulations. After companies have created a more CE-focused business model, they can set clear CE goals and commit to these early on. All players need to be included in the design phase, making use of their specific knowledge. Economic interest and collaborations can be aligned through new forms of contracts. When these steps are cleared, the design principles showed in the previous research question can be implemented.

The third research question is *"which obstacles might interfere with the implementation of CE practices in the design phase?"* One of the main barriers mentioned by the interviewees is the lack of incentive to use CE practices. Due to the lack of incentive, companies are not really focusing on transitioning to a CE, as they lack interest and motivation. This leads to a lack of knowledge resulting in limited CE practices. Regulatory barriers mentioned are the lack of CE-focused regulatory frameworks and changing regulations on reuse of materials. The fragmented state of the building industry and the current CE-unfriendly building block were also seen as barriers, as well as the lack of a physical and digital CE market for materials. In the design phase, barriers are focused on lack of CE design and lack of standardization. Lastly, economic barriers mentioned are high start-up cost, lack of short-term income and lack of use and knowledge on LCC calculations.

The fourth research question is *"how can the obstacles, which interfere with the implementation of CE practices in the design phase of buildings, be overcome?"*
Incentive for the building owner is created by setting up regulations focusing on materials reuse, waste production or environmental impact. High start-up costs and lack of short-term ROI can be solved when contractors change towards a PaaS business model. Initial investments costs will become lower for building owners and contractors will have a constant cash-flow. LCC calculations will become more needed and will thus be developed, and more used. The lack of CE knowledge can be overcome by building CE pilot projects. When a digital overview is created of the current building block, a supply market is formed. Architects can use this in order to design new buildings, which again creates a supply if designed in circular way. Incentive for suppliers will be created when building owners request circular materials, due to a changing market. The government needs to provide a guarantee on whether circular materials can be used again to stimulate the production procurement of these materials.

6.3 Theoretical implications

This research focuses strictly on the building construction industry. Besides this, a focus has been put on the design phase. Within the design phase, further focus has been put on barriers and drivers in order to create a CE focused design phase. In this study, a clear relation has been shown between the barriers before the design phase and its impact on the design phase, which was lacking beforehand. The findings in this study contribute to both the CE and the building construction literature by showing how to create a CE-focused building construction industry.

Furthermore, this study shows that there are several barriers to overcome before CE practices can be implemented. It is also shown that that these barriers are interconnected and can be tackled in a trickle-down order, starting with the creation of incentive for CE design for building owners, resulting in the implementation of CE practices in the design phase. Barriers overcome in between these stages focus on project design, lack of a circular market and economic barriers. As a result, this thesis contributes to knowledge on CE practices related to the design of buildings. The findings can be applicable to similar industries abroad. However, local regulations do have an effect of the findings of this study.

6.4 Managerial implications

In order for companies in the building construction industry to become more CE-oriented, several methods are proposed. One method focuses on letting the building construction industry become more CE-oriented by learning from pilot projects. The other two methods are regulations which need to be implemented by the government. Companies should have early commitment to CE goals and need to work together from early on, by using collaboration contracts to complete these goals. During the design phase, focus should be put on all lifecycle stages.

The current building block should be visualized digitally, in order to start a digital supply which can be used by architects. Suppliers need to start producing circular materials following the market. Suppliers also need to change towards a PaaS business model in order to create cash-flow for themselves and to create less initial investment for building owners.

The government needs to give the guarantee that circular materials can be used again to ensure its procurement.

6.5 Limitations of the study

This study is limited to five companies, where one informant from each company was interviewed. This is not sufficient to cover all aspects of CE practices in the construction industry. Besides, the personal opinion and commercial interest of the interviewees can also have an effect on the answers given. Also, a company is not represented by one single interview. As this study focuses mainly on the design phase, it could be that implications are more difficult to put in practice than it seems in the design phase.

6.6 Areas of further research

Further research is needed on how incentives can be created for the building owners so that they start demanding CE practices. Different methods of incentive creation should be considered such as regulations and change from within companies. Another area of study could be on the creation of a standardized building construction industry, as this is a necessary but difficult step. Another focus point could be towards the creation of a circular marketplace, as this as well is a crucial step. Another area could be a similar type of study as the one performed in this thesis, focusing on CE in the design phase, but specified towards a certain type of building, such as museums or office buildings.

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Appendix

Interview guide

General Questions:

1. Can you start by telling me about your company?
2. Can you describe the process of how you design the building or part of the building you are creating?
3. Can you describe what your supply chain looks like?

Circular Economy (CE)-related Questions:

4. Can you tell me about your company's experience with the circular economy in the construction industry?

5. Can you provide some examples of circular economy practices that you have implemented or are considering implementing?

   a. What went well and what could have been improved?

6. Are there any laws or regulations that you feel are pushing you or holding you back from becoming more sustainable or circular?

Questions Related to the Design Stage: Now I would like to delve deeper into the design stage. The research is more focused on this. By design stage, I mean the phase where plans are still on the drawing board and no physical construction has started yet. I want to know if you consider aspects such as location, building materials, energy, and building use when designing the building, and to what extent you consider these.

7. In this design process, is there a protocol that can or must be followed to create a circular product?
8. What CE practices can be implemented in the design phase of constructing office buildings?
9. During the design phase, have you been mindful of:

   a) How to reduce the eco-footprint

b) How materials can be collected in a circular manner

c) How the physical construction of the building can be done in a more circular way

d) How the building will be used

e) How end-of-life is organized

f) Actively collaborating with other companies in the design phase to achieve a circular design.

  - Do you believe collaboration between companies is important to become more circular?
  - Are you satisfied with your collaboration efforts?

10. For each of the 6 questions above: why do you consider it in the design phase or why not?
11. Of the 6 methods mentioned above, which one do you think has the greatest potential for success within the design phase of your company?
12. What steps need to be taken to create a design phase that focuses more on the circular economy?
13. What barriers can disrupt the implementation of CE practices in the design phase?
14. How can these barriers be overcome?