Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Economics and Management
Dept. of Industrial Economics and Technology Management

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Circular economy in construction sector: barriers for scaling up construction materials reuse in Trondheim region, Norway

Master's thesis in Globalisation and Sustainable Development
Supervisor: John Eilif Hermansen
July 2020

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Precursor of the study and its evolution

The work on this study started with meetings with Per Eric Sørås and Lillian Strand from Trøndelag County Council, Department of Planning, Industry and Cultural Heritage and John Eilif Hermansen (Supervisor, NTNU), in November 2019 where we discussed possible cooperation for my Master thesis and relevant areas for research project. Circular economy is the topic of my interest and one of areas presented by the Trøndelag County Council, dealing with circular economy transition, was construction sector and materials reuse. On the second meeting in January, we signed a cooperation agreement and agreed on "Circular economy in construction sector" topic. I also got recommendations for further contacts with potential participants from Trøndelag County Council, Trondheim Municipality and GreenStock. The same day later, I had a meeting with the Trøndelag County Council, Trondheim Municipality and GreenStock representants, where they discussed progress of their fellow project for materials reuse scaling up with implementation of GreenStock digital platform. Thus, I got contacts of interesting and relevant participants for my research.

On meetings with John Hermansen in January I got contact of relevant participant from SINTEF. Thus, I chose to invite 5 participants to take a part in my research: Trøndelag County Council, Trondheim Municipality, GreenStock, SINTEF and Øystein Thommesen AS architect. All of them play important roles in the construction sector in Trondheim.

The idea was to engage actors from different areas of construction industry to evaluate their vision on the "construction materials reuse" phenomenon from different perspectives. In construction sector decisions are taken on different stages of the process and different actors take part in and influence those decisions. For instance, many decisions are taken on the design stage, that is why I invited architect company Øystein Thommesen AS. The other important area is research, development, and innovation. SINTEF was chosen to represent this area. The other very important area is law and regulation on material use and reuse that is why the Trøndelag County Council and Trondheim Municipality were chosen, as they are dealing with implementation of those regulations. And of course, start-ups and innovation companies in construction area play an important role for stimulation and actual progress in this area. GreenStoch is a good example of such innovative projects. In more detail, I will present them in chapter 4 Empirical data. Thus, all participants were invited to participate in my project. I sent e-mails with invitations where I shortly presented myself and the aim of my research and attached informational letter where aims of my project were described in detail, considering moral and ethical rights of participants. I also sent them an empty SWOT analysis form with detailed guidelines on how to fill it. All of them agreed to participate in my project. Further, they had to sign an agreement form for participation, fill in the SWOT analysis form and have a short meeting with me, where we should have discussed SWOT-analysis form and have done some short interview were I planned to ask them about their involvement in construction materials reuse projects and initiatives.

Because of the COVID-19 outbreak and preventive measures in form of social distancing and self-isolation, most people were forced to work from home, schools and kindergartens were also closed. That meant that people had to combine work and taking care of kids, which is often challenging. As a result, people got delay in their job tasks and a lot of not answered emails in mailboxes.

Me myself, as a student and mother of two small kids, without access to kindergarten also got delayed with my master thesis project.

However, the study has evolved based on information from the participants which managed to fill in the SWOT analysis form, literature review and feedback from supervisor.

Problem description

The main aim of the study is to present current situation of circular economy and materials reuse in the construction sector in the EU and in Norway and to identify and analyze existing challenges/barriers for construction materials reuse scaling up in Trondheim region, Norway.
Main content:

- Explanation of link between waste and circular economy.
- Legal framework for circular economy transition in EU and its relevance for construction sector. To understand targets and requirements which EU set for waste management.
- Overview of actions which should be taken on the transition way to circular economy in construction sector. Vision of future construction sector in the circular economy environment. Challenges on the way to circular economy actions in construction sector.
- Reuse as a bridge between waste prevention and the circular economy. Presentation of challenges for increasing reuse, opportunities, and benefits from scaling up construction materials reuse in the EEA.
- Overview of construction sector current situation, statistical data on construction and demolition waste treatment in the EEA countries. Comparison of construction and demolition waste treatment situation in Norway and in other EEA countries.
- Legal, framework for materials reuse in Norway.
- Case study with local actors on the construction materials reuse in Trondheim region. Analysis of challenges and barriers for materials reuse scaling up in Trondheim region. Recommendations for possible solutions.
- Discussion of the reliability and validity of the study and conclusion.

Assignment is given 15 January 2020
Supervisor: John Eilif Hermansen

Preface

This document is my Master Thesis in MSc Globalization and Sustainable Development at the department of Industrial Economics and Technology Management at the Norwegian University of Science and Technology (NTNU) in Trondheim.

I would like to thank my supervisor John Eilif Hermansen, Associate Professor at IØT, NTNU, for guiding me along the Master Thesis writing, for his support and understanding in this pandemic period related to COVID-19 outbroke, for giving me valuable advises and helping me with creation of network for research development.

I also wish to thank Per Eric Sørås and Lillian Strand from Trøndelag County Council, for their time in the initial phase of this study, helping me in choice of topic, taking part in my research and connecting me with GreenStock and Trondheim Municipality.

I would like to extend my gratitude to my husband Vitalii, and my kids Nikita and Camilla for the biggest and the warmest support during this period.

Abstract

Construction industry is the largest consumer of resources and raw materials in the world. This industry is responsible for approximately 40% of total waste generated in the world and contributes significantly to the release of carbon dioxide. Recently, emerged stricter environmental regulation in the world put the construction sector under increasing pressure to reduce raw material consumption and its environmental impact.

The circular economy approach can help construction sector to minimize its footprint, and avoid rising prices, delays, and other consequences of resource scarcity. Reuse plays an important role in the circular economy model. The reuse of construction materials and components has high potential in reducing negative environmental impacts, related to the extraction, processing and production of construction components and materials and reducing construction costs, and also could cause community benefits through providing training and work places for many people (European Construction Sector Observatory, 2019).

According to Eurostat (2019), among construction and demolition waste (C&DW) management options in Norway, recycling is prioritized and constitutes approximately 57% of total amount of construction and demolition waste treatment. At the same time, landfill disposal, which is on the lowest rank in waste management hierarchy, constitutes more than 30% of total C&DW management in Norway. In comparison to other European countries, Norway has almost the highest rate of construction and demolition waste landfilling. Thus, this study focuses on identification of challenges/barriers on the way for scaling up construction materials reuse, which is on the higher rank in waste management hierarchy than recycling and should be prioritized measure for waste treatment in future. This study shows that main barriers for materials reuse in Trondheim region's construction sector are interconnected and linked to an underdeveloped market for professional players, quality of secondary materials, legal issues, traceability, technological challenges, and responsibility issues. As an outcome of analysis of identified challenges/barriers, recommendations that can be used by different actors are proposed.

Contents:

Acronyms

BIM – Building Information Modelling

CE – Circular Economy

CEAP – Circular Economy Action Plan

C&DW – Construction and demolition waste

DOK – Regulation on documentation of construction products

EEA – the European Economic Area

EU – the European Union

GHG – Greenhouse Gas

LCA – Life Cycle Assessment

RFID – Radio-Frequency Identification

TEK – Technical Regulations

WFD – The Waste Framework Directive 2008/98

WWF – World Wildlife Fund

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1 Introduction

The main aim of this study is to present the current situation of circular economy transition, construction and demolition management and materials reuse in the construction sector in the EU and in Norway and to identify and analyze existing challenges/barriers for construction materials reuse scaling up in Trondheim region, Norway. This study will also present recommended actions for overcoming the identified barriers for materials reuse.

1.1 Background

The construction sector accounts for 6% of global GDP and has total annual revenues of near €9 trillion and €3 trillion of added value. The construction industry is expected to grow significantly in the coming years and estimated to be around €13 trillion of revenue by 2025. More than 100 million people are employed in construction sector worldwide today. The construction industry has considerable interaction with other sectors because value creation frequently occurs within or by means of buildings or other forms of construction assets. Thus, we can see that construction sector is a significant part of the world economy (World Economic Forum & The Boston Consulting Group, 2016).

At the same time, the construction industry is the largest consumer of resources and raw materials in the world. It consumes 50% of total steel production in the world. Every year 3 billion tons of raw materials are used for manufacturing of construction products and materials worldwide. The construction industry is responsible for approximately 40% of total waste generated in the world. The industry is responsible for 25-40% of global energy use, thereby contributing significantly to the release of carbon dioxide (World Economic Forum & The Boston Consulting Group, 2016).

In 2016, the construction sector in the EU produced 923 million tons of waste. In terms of volume, it is the largest waste flow in the EU, that represent 30% of total amount of waste generated. "Construction and Demolition Waste (C&DW) refers to the waste generated from general construction activities and includes concrete, bricks, gypsum, wood, glass, metal, plastic, solvents, asbestos and excavated soil" (European Construction Sector Observatory, 2019).

Global demographic and lifestyle trends cause increasing demand for material resources, many of which are scarce. The aim of emerged stricter environmental regulation in the world is to protect fragile ecosystem of our planet, it makes extraction and use of certain resources harder and more costly. This means that the construction sector is under increasing pressure to reduce raw material consumption and its environmental impact.

According to European Construction Sector Observatory (2019), the concept of circular economy refers to the idea of the better and more efficient use of resources, which correspondingly means the reduction of waste generation. The circular economy represents a shift from the traditional linear flow of materials consumption pattern of 'take-make-consume-dispose' economic growth model (see Fig.1), to a sustainable system, which aims at reduction of virgin resources use, generation savings through improvement of secondary resources use, and decreased negative environmental impact (European Construction Sector Observatory, 2019). Thus, the circular economy approach can help construction sector to minimize its footprint, and to avoid rising prices, delays, and other consequences of resource scarcity. The circular economy gives the potential to save € 65 billion in primary resources by 2030 in the EU. This transition would involve changes in the way projects are designed, procured, constructed, operated, and repurposed currently (Arup, 2016).

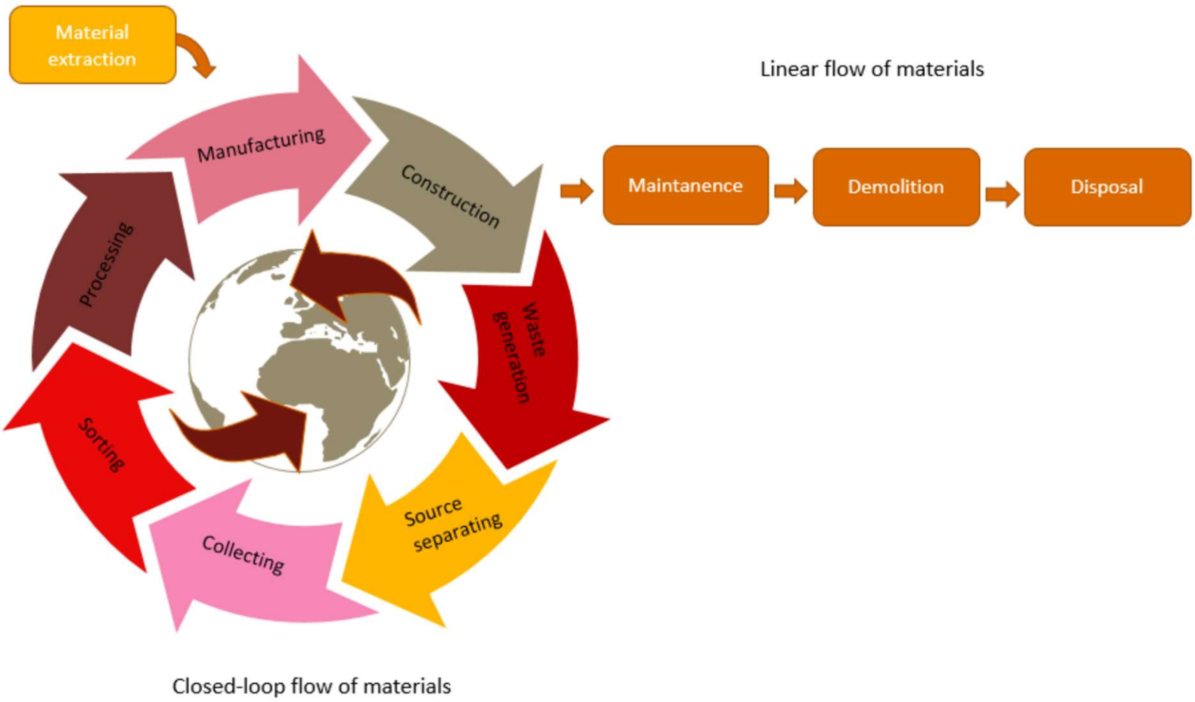

Figure 1: Linear and closed-loop model of C&DW

Source: (European Construction Sector Observatory, 2019)

Reuse plays an important role in circular economy model. The reuse of C&DW materials and components have high potential in reducing of negative environmental impacts, related to the extraction, processing and production of construction components and materials and reducing

construction costs, and also could cause community benefits through providing training and work places for many people (European Construction Sector Observatory, 2019).
According to European Environmental Agency report (2018), "*Reusing products and components at the end of their use phase can reduce waste generation and potentially save natural resources by extending the use phase of products at the same time. Reuse, as well as preparation for reuse, can thus provide a link between the waste hierarchy of the Waste Framework Directive, on the one hand, and the European Commission's Circular Economy Action Plan, on the other"(EEA, 2018)*
From the perspective of waste prevention and generation of secondary products and materials, circular economy and materials reuse are certainly boosting a more efficient use of material resources, opening new markets, developing new skills and business. Considering Construction and Demolition Waste (C&DW), namely the subject of the waste hierarchy (Directive 2008/98/EC, 2008), that reflects priority order in waste prevention and management, reuse as waste preventive measure, deserve some further reflection with focus on different impacts of reuse and recycling.
Despite this, EU legislation does not point out some specific targets for reuse, and much of waste streams, that was diverted from landfill, has been recycling in a way that generate mainly lower value products (downcycling) (Talamo, 2020).

1.2 Circular economy potential for construction sector in Norway

The construction industries accounted for almost 10% of GDP in 2018 in Norway. The construction sector employed approximately 280,000 people in 2019 (Grønn Byggallianse & Norsk Eiendom, 2016). According to Deloitte (2020), that has been commissioned by the Ministry of Climate and Environment to design a national knowledge base on circular economy in Norway, which will serve as base for development of a national strategy for circular economy, the construction sector has a central impact on increased circularity by setting requirements for location, functionality and quality in buildings, requirements for material and energy use in new and rehabilitated buildings, and through property management. The industry has a potential to develop on all indicators of increased circularity, but has a special potential in better land use, better maintenance, and increased use of circular materials. There are also significant potentials associated with increased use of materials suitable for repair and reuse, and work to reduce waste volumes and increase materials reuse and recycling. (Delotte, 2020).

The industries have a high consumption of virgin materials and a high proportion of waste that is not reintroduced into the economy. Construction is the largest single source of waste in Norway. It is estimated that as much as half of a building's impact on the climate is due to the use of materials. The current building technical regulation TEK 17 imposes certain requirements for material use, such as selecting products that are suitable for reuse and material recycling (Delotte, 2020).

The industry itself estimates that in connection with the construction of new buildings, there may be as much as 20% waste of building materials. A large proportion of the waste constitutes fully usable materials and products, such as plasterboard. Access to cheap materials provides few incentives to calculate exact quantities, and in connection with many construction projects, more building materials are often purchased than is needed. Industrialized production, such as the use of pre-cut materials and prefabricated items, can contribute to reduce wastage such as trimming and the like at the construction site (Delotte, 2020).

Large parts of the environmental impact are determined during the design phase through material selection and choice of solutions that enable reuse and material recycling, and it is therefore crucial that builders and property managers think circularly from the start of a building or renovation project in order to realize the potential for circularity. Planning with the long lifetime for new buildings and extending the life of existing building stock are key strategies for increased circularity. Ensuring flexibility in floor plans and technical facilities is important to be able to adapt changes in functions and needs, and to reduce the need for major renovations. Buildings must therefore be designed in such a way that the materials can be dismantled and reused. This could mean, for example, the need for new types of module-based materials and other types of materials and components that are easy to repair and reuse development (Delotte, 2020).

Today, mainly virgin raw materials are used, and there is little reuse and use of recycled materials in the building, construction, and real estate industries. This happens mainly because access to most virgin raw materials is good and cheap compared to using secondary raw materials. However, the use of regenerative materials such as wood has increased in recent years, helping to reduce the use of concrete and steel in building structures. Increased reuse and use of recycled materials requires stable access to these raw materials and increased insight into the quality, properties and possible content of environmental toxins. Today, it can be difficult to provide documentations which can ensure that existing materials in buildings meet technical requirements in accordance with the regulations. This leads to limited possibilities of reuse. Through the Kristian Augusts gate 13 project in Oslo, where the real estate company Entra has renovated and built on one building only by means of reuse, the company points out that it is time and resource consuming to find necessary materials suitable for reuse, partly because they often lack the necessary documentation on the quality and properties of the consumable materials. In the Netherlands, the building, construction, and real estate industries have tried to find a solution to this by developing an information database on materials available for reuse. In connection with remediation, remodeling and rehabilitation of buildings, there is a potential for new circular business models in construction sector.

In its roadmap for green competitiveness, the real estate industry has set its own targets for the industry on closed material cycles by 2050. It also have targets for zero emissions of pollutants in 2050, and a 40% reduction of emissions from building (Grønn Byggallianse & Norsk Eiendom, 2016). Thus, we can see that Norwegian construction sector has big ambitions a huge potential in circular economy, but at the same time we can see that there are still many barriers preventing implementation of such mechanisms as materials reuse.

1.3 Research questions

This study aim is to answer following questions:

1. What role the issue of waste plays in effectivization of resources use through circular economy?
2. Which actions should be taken to improve Construction and Demolition waste management? How future construction sector will look like in circular economy environment and which barriers emerge on the way of those actions?
3. Why reuse is an important tool for circular economy transition?
4. What is the current situation in construction sector in Norway in comparison to other EEA countries?
5. Which challenges/barriers emerged for scaling up of construction materials reuse in Norway and particularly in Trondheim region? How to overcome those challenges/barriers?

The first question will be mainly addressed in the section 3.2 and 3.3 where we will see why issue of waste management is linked to effectivization of resources use and transition to more sustainable economy in circular economy perspective. The section 3.3 will help us to understand the legal framework for circular economy transition link with waste management. This section presents legal framework of circular economy transition on the EU level. This is done because the Norwegian circular economy activities largely evolve from the EU's circular economy work. The second question will be answered in the sections 3.4, 3.5, 3.6. Those three sections will help us understand what should be done on each phase of construction lifespan to transform construction sector to a more sustainable one, how different phases of building lifecycle can look like in circular environment in future and, which challenges construction sector meet on the way to circular economy implementation. The third question will be answered in the section 3.7. In this section, we will see the role of reuse as a bridge between waste generation prevention and the circular economy and consider challenges that materials reuse model meets on its way and which opportunities it offers for construction sector. The fourth question will be answered in the sections 3.8 and 3.9. In the section 3.8 we will see some statistical data that will help us to understand a current situation of construction and demolition waste treatment in EEA countries and to compare Norwegian situation to other countries. The section 3.9 will present us existing legal framework for construction sector in Norway and how it is related to reuse. This section is based on Asplan Viak report. To answer the last question, empirical data was collected and explained in chapter 4, analyzed in chapter 5 and the outcome is presented in chapter 5.

As it can be seen, the approach starts from the extended focus and moves to a more specific one. The outcome of this study is the list of recommendations for overcoming of identified challenges/barriers for scaling up construction materials reuse in Trondheim region in Table 9.

1.4 Structure of the study

The study starts from Introduction chapter which will be followed by Method chapter. The Method chapter followed by the Theoretical framework chapter with overview of definitions, concepts, and context literature. The Theoretical framework is followed by the presentation of Empirical data and Analysis. The results are presented in Analysis chapter. The validity and reliability had been discussed in the next chapter. At the end of the study, the Conclusion chapter summarizes the main findings.

1.5 Limitations of the study

The first limitation was related to the literature, the literature is mainly related to Construction and Demolition waste management phase instead of prevention phase through reuse of materials. Also, even if reuse is presented in circular economy framework as important tool for improvement of material use effectivization and decrease of environmental impact, there is no regulations and standards that are created specifically for secondary materials use realization.

The second limitation was related to period of research conduction. The topic was chosen in January, in March and April work was frozen due to outbreak of COVID-19. This made execution time for conduction and evaluation the research roughly four months. This research was not planned to go deep in many topics, but within given time it tried to gain and give an overview about the topic of circular economy in construction sector with focus on materials reuse with case study in Trondheim region. The other limitation was related to data collection, that was complicated by COVID-19. As a result, three instead of five participants filled in SWOT-analysis form. This mean that collected data is not complete as initially planned, but one can see that many identified in Trondheim region challenges/barriers are reflecting in those listed in Asplan Viak and Wahlström reports. Therefore, we can conclude that this research, even with limited number of participants, managed to identify main challenges/barriers for scaling up materials reuse in Trondheim region.

2 Method

2.1 Research model

This study follows qualitative research methods. The aims of qualitative methods, for the most part, are to achieve understanding of the phenomenon in depth while quantitative methods place primary emphasis on generalization on some theory or hypothesis (Patton, 2002). Qualitative method is a good option in conditions with limited time and resources.

Phenomenological study is an appropriate qualitative method when the aim of study is to describe and understand an event, activity, or phenomenon. Usually, in phenomenological study the combination of different methods such as literature review, document reading, watching videos, conducting interviews are applied to understand meaning participants place on phenomenon of interest. Researcher relies on the participants' own perspectives to make some assumption regarding the phenomenon. While conducting phenomenological study, researcher has not a well-formed hypothesis in the beginning of the process. Usually, to build a sufficient dataset and to validate research findings 5-25 interviews are conducted (Langdridge, 2007).

Purposeful sampling technique was applied for this study. This technique for identification and selection of participants is widely used in qualitative research when resources are limited. Purposeful sampling involves identification and selection of individuals which have knowledge and experience about phenomenon of interest. In addition, availability, and willingness to participate play an important role for selection of participants (Creswell & Plano Clark, 2011). Thus, as an aim of the study was to get evaluation (based on personal experience and knowledge) of the "construction materials reuse" phenomenon from different actors of the construction sector in Trondheim. Interesting and relevant actors of this sector were selected based on thorough analysis.

In this study, different types of methods for data collection were combined, such as literature review and SWOT analysis. With the help of these methods, the study should be reliable and valid.

The collection of data for this study was complicated by the outbreak of COVID-19 in the world. Initially, it was planned to collect data from different actors of construction sector in Trondheim. In total, 5 participants were invited to take a part in this study, they agreed on participation, but because of quarantine situation, where people had to work from home without access to offices, data collection was not fully completed as planned. It was difficult to get responses from the selected participants and not all planed meetings were fulfilled. The process of paper writing was also complicated for me as a mother of two small kids, when kindergartens were closed.

2.2 Research Design and Data Material

The research design of this study has been composed by literature review and a close cooperation with Trondheim Municipality, Trøndelag County Council and GreenStock. The main aim of the study is to present current situation of circular economy and materials reuse in the construction sector in the EU and in Norway and to identify and analyze existing chellenges/barriers for construction materials reuse scaling up in Trondheim region, Norway. Literature search showed that construction materials reuse is a relevant topic in the world, because of scarce stock of raw materials, but at the same time this phenomenon is on its initial stage of development. Further in this paper challenges/barriers for construction materials reuse will be investigated and some recommendations for overcoming of those barriers will be suggested.

Data material has been collected through literature search for published materials and through SWOT analysis form filling by selected participants, and by personal communication with participants for unpublished materials. The main foundation for the analysis is represented by Trøndelag County Council, Trondheim Municipality and GreenStock for unpublished materials and Asplan Viak (2018) report on barriers for construction materials reuse: "Utredning av barrierer og muligheter for ombruk av byggematerialer og tekniske installasjoner i bygg"; Arap (2016) report "The Circular Economy in the Built Environment"; Wahlström et .al. (2020) report "Construction and Demolition Waste: challenges and opportunities in a circular economy"; and Migliore, et. al. (2020). report "Strategies for Circular Economy and Cross sectoral Exchanges for Sustainable Building Products. Preventing and Recycling Waste" for published materials.

2.3 SWOT analysis and personal communication

In total, 5 actors were considered relevant for the SWOT-analysis form filling in. They were contacted via mail. Table 1 shows which actors that have been contacted. The green slots are actors that have been contacted and gave significant contribution for data collection for this project by filling in SWOT-analysis form. The red slots are actors that have been contacted, that agreed to participate in research, but have not filled SWOT-analysis form conceivably due to COVID-19 outbreak.

Table 1. Overview over research participants

Actor	Time communicated
Trondheim Municipality	2020: February, March
GreenStock	2020: February, April
Trøndelag County Council	2019: November; 2020: February, March, April
SINTEF	2020: March, April (not succeeded)
Øystein Thommesen AS	2020: March, May (not succeeded)

3 Theoretical framework

In this chapter, theoretical framework relevant for this study will be presented. The study's approach is multidisciplinary one, therefore theoretical part will also contain context literature related to four main disciplines circular economy, construction and demolition waste, construction sector and materials reuse. First, important definitions and concepts will be clarified. Then, links between circular economy and waste will be considered. Further, legal framework for circular economy implementation with introduction of many related to waste management terms, on the EU level will be presented. Since focus of this paper is circular economy in construction sector, it is also important to define how the circular economy can be implemented into construction sector. Therefore, some actions that should be taken on every phase of a building lifespan during circular economy implementation will be presented. To understand how circular economy can change construction sector in future, vision of construction sector in circular economy will be presented. Since empirical part of this paper will be focused on evaluation of challenges and barriers for scaling up materials reuse in Trondheim region, Norway, in theoretical part challenges on the way to circular economy actions that were defined in (Wahlström et al., 2020) report will be also included. This part of theory is important because Wahlström table of challenges will be used as a basis for analyzing of data collected through SWOT-analysis. Then, reuse as a bridge between waste prevention and the circular economy and barriers for reuse in the EU will be presented. Next, we will see the current situation in construction sector in the EEA countries. Here, some statistical data on waste management in EEA countries will be presented and compared to Norway. Many barriers for materials reuse scaling up are related to legal issues, that is why legal framework for construction sector and its relevance to materials reuse in Norway will be also included in theory part.

3.1 Definitions and concepts

Table 2: Definitions

Circular Economy	*"**The circular economy** is based on an emerging economic model that covers both techniques and business models to keep materials and resources in use as long as possible, and ideally forever, in a closed cycle of extended use, reuse and recycling"* (Circle Economy, 2018).
***Construction and demolition waste** (C&DW)*	*«**Construction and demolition waste** (C&DW) refers to the waste generated from general construction activities and includes concrete, bricks, gypsum, wood, glass, metal, plastic, solvents, asbestos and excavated soil»* (European Construction Sector Observatory, 2019).
Preparing for re-use	*«**Preparing for re-use** means checking, cleaning or repairing recovery operations, by which products or components of products that have become waste are prepared so that they can be re-used without any other pre-processing»* (Directive 2008/98/EC, 2008, Art. 3).
Re-use	*«**Re-use** means any operation by which products or components that are not waste are used again for the same purpose for which they were conceived»* (Directive 2008/98/EC, 2008, Art. 3).
Recovery	*«**Recovery** means any operation the principal result of which is waste serving a useful purpose by replacing other materials which would otherwise have been used to fulfil a particular function, or waste being prepared to fulfil that function, in the plant or in the wider economy»* (Directive 2008/98/EC, 2008, Art. 3).
Recovery rate	*«the amount of C&DW that is prepared for reuse, recycled or subject to material recovery, including backfilling, divided by the C&DW treated» (Eurostat, 2019)*
Recycling	*«**Recycling** means any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes. It includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations»* (Directive 2008/98/EC, 2008, Art. 3).
Transition to circular economy	*"The transition to a more circular economy, where the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste minimized, is an essential contribution to the EU's efforts to develop a sustainable, low carbon, resource efficient and competitive economy" (COM (2015) 614, 2015, p. 2).*

3.1.1 Linear construction environment

Linear construction can be characterized as a 'take-make-consume-dispose' process. This process assumes no limit on a raw material resources availability. Finite primary or non-renewable resources are extracted from nature and used in construction materials. These materials become parts of buildings and in the end of the functional life cycle and demolition of building, these materials are disposed of mainly as waste or in low-value applications. Thus, in a linear constructing environment, materials are losing their chance to be reused in future. Sustainability efforts are focused on ecoefficiency: maximization of economic growth, with minimization of environmental impact (for example: amount of waste disposed per Euro turnover per product group). In a linear construction environment, ownership of a building (including construction, content and surrounding) is transferred from one owner to next.

Together with ownership, responsibility for all actual and future economic, social, and environmental impacts, is taken over. On each stage of ownership (planning, design, construction, use and demolition), the owners are responsible only for their own actions and there is very limited notion of the next step and next responsibilities. The characterizing components of the linear economy are single use, downcycling, programmed obsolescence, legacy substances or loss of value (Circle Economy, 2018).

3.1.2 Circular construction environment

In a circular economy use of resources is decoupled from economic growth. This means that economic development no longer relies on the same amount of resources consumption. Resources are used more efficiently, and the economy depends less on nonrenewable resources. *"The circular economy is based on an emerging economic model that covers both techniques and business models to keep materials and resources in use as long as possible, and ideally forever, in a closed cycle of extended use, reuse and recycling"* (Circle Economy, 2018). The characterizing components of the circular economy are: renewable materials, industrial symbiosis, shared economy, a cloth relation between producer and consumer, proximity economics, 'product as a service', reuse, recycling and upcycling, detoxification of material cycles, urban mining and sustainable consumption and production (Circle Economy, 2018).
"In traditional building projects, working intensively with suppliers is not common practice for architects. In a more circular economy suppliers and architects will need to share responsibilities" (Circle Economy, 2018).

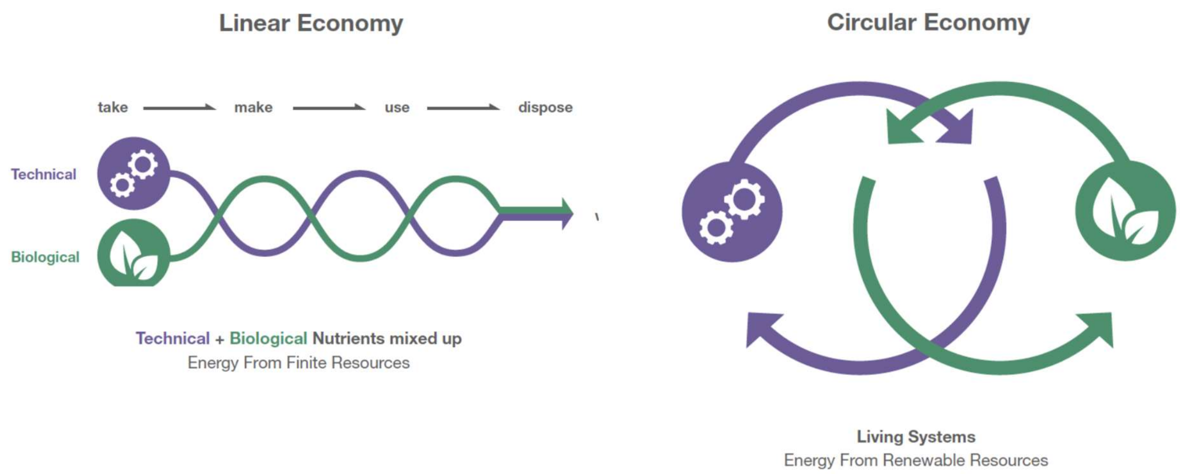

Figure 2: Linear economy in comparison to circular economy
Source: (EllenMacArthur Foundation, McKinsey Centre for Business and Environment, & SUN, 2015)

3.2 From Waste to Circular Economy

In the last decade, the European Commission has been focusing its efforts, through numerous initiatives, on transformation of Europe's economy into a more sustainable one. Within this vision of transition to more sustainable circular economy, the issue of waste plays an progressively important role, increasing from a broad scenario of strategies and policies for the environment, closely related to objectives that concerning, simultaneously, economic and social growth, and changing production and consumption processes and patterns (Migliore, Talamo, & Paganin, 2020). In this section we will study how the issue of waste is linked to circular economy and which benefits circular economy offers to construction sector.

It is clearly reflected in COM(2014)398, how the issue of waste is the link between environmental, economic and productivity goals, in the perspective of the circular economy: *"Circular economy systems keep the added value in products for as long as possible and eliminates waste. They keep resources within the economy when a product has reached the end of its life, so that they can be productively used again and again and hence create further value. Transition to a more circular economy requires changes throughout value chains, from product design to new business and market models, from new ways of turning waste into a resource to new modes of consumer behavior. This implies full systemic change, and innovation not only in technologies, but also in organization, society, finance methods and policies. Even in a highly circular economy there will remain some element of linearity as virgin resources are required and residual waste is disposed of "* (COM (2014) 398, 2014, art. 1).

Circular economy means system-wide changes that are based on the aim of keeping materials and products at their highest value as long as possible through actions on recycle, remanufacture and reuse. The circular economy approach is focused not only on environmental goals but also on realization of economically attractive opportunities, such as increase resources productivity, reduce virgin resources dependence, and waste generation, and increase employment and growth. Statistics and various studies estimate and highlight the economic opportunities in circular model of economy. For example, the study, developed by Ellen MacArthur Foundation, McKinsey Centre for Business and SUN, evaluates that Europe will increase resource productivity by up to 3% yearly, generate a primary resource benefit of as much as €0,6 trillion annually by 2030 to Europe's economy and €1,2 trillion in non-resource and externalities benefits, bringing in total around €1,8 trillion more versus today. This study also predict a GDP rise of as 7% relative to current development scenario with positive impacts on employment (EllenMacArthur Foundation et al., 2015).

This study says also that the transition to circular economy implies new models in production and consumption with use of integrated approaches to products, services and waste: *"The smart rebound of the European economy will require game-changing strategies, breaking the paradigms prevailing since the industrial revolution. A priority is to go beyond the linear economy, where stakeholders are in traditional silos. In addition to preserving natural resources, shifting to a circular economy offers an opportunity to create new sources of wealth. The emergence of innovative models leads to collaborative dynamics across industries, cities, and communities that reveal new fields of sustainable value creation, such as selling services instead of products, recovering resources from waste, sharing assets, and producing green supplies. Europe offers the perfect ground for a circular economy to truly take shape and for launching disruptive models. It represents a unique opportunity but will require true vision and leadership" (EllenMacArthur Foundation et al., 2015, p. 6).*

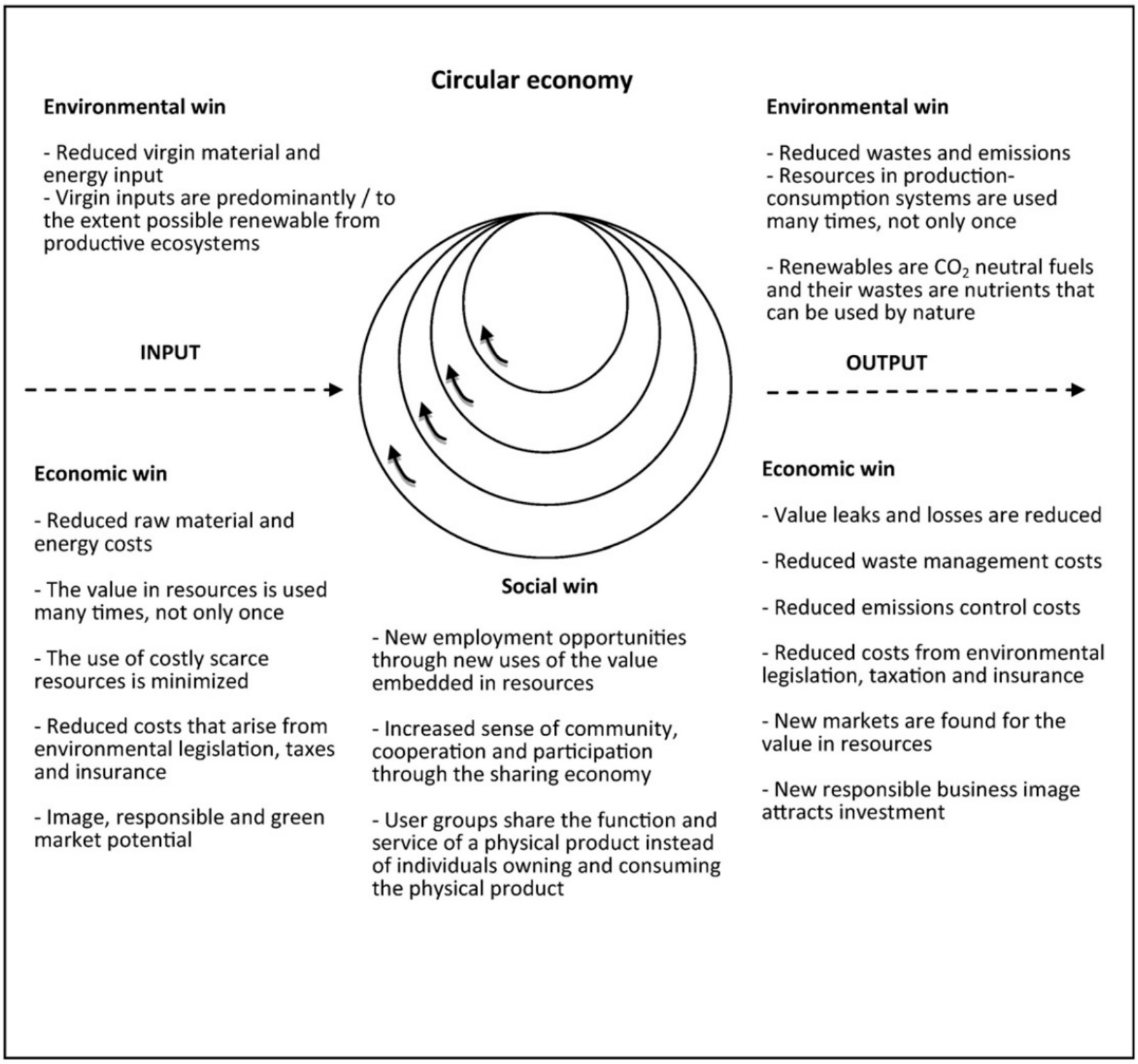

Figure 3: Circular economy's environmental, social, and economic benefits.

Source: (Korhonen, Honkasalo, & Seppälä, 2018)

3.3 Legal Framework EU

Recently, environmental policy has become progressively important for improvement of resources use efficiency. This caused increased focus on the development of circular economy. From the perspective of environmental economic, a circular economy means that *"the greatest possible prosperity is created at the lowest possible resource use and costs*" (Høibye & Sand, 2018a).

This applies at European level, through the EU Commission's circular economy package that aims to help European businesses and consumers fulfil the transition to a stronger and more circular economy with more sustainable way of resources use. It also applies at national level through initiatives in the Nordic countries where the work incorporates all stages in the waste hierarchy, from prevention and waste reduction to reuse and recycling, recovery and disposal (Høibye & Sand, 2018a)

3.3.1 The Circular Economy Action Plan

In December 2015, the European Commission formally adopted a Circular Economy Action Plan (CEAP) the aims of which are stimulation of Europe's transition to a circular economy, fostering a resource-efficient and competitive economy, generate new jobs and boosting global competitiveness (COM (2015) 614, 2015). CEAP is a set of voluntary initiatives and regulatory actions aimed at improvement of production, consumption, waste management and secondary raw materials. In Table 5 below, an overview of the actions that characterize the CEAP and are oriented to support the circular economy all along the value chain, taking into consideration production, consumption, repair, remanufacturing, waste management and secondary raw materials, are listed. Regarding some strategic areas, such as construction industry, the CEAP aims at stimulating sustainable activities through legislative proposals, new business opportunities (such as eco-design), development of innovative approaches, and funding of projects through the EU's Horizon 2020 research program. The CEAP highlights the role of waste in all the actions that support the transition to a circular economy: *"The transition to a more circular economy, where the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste minimized, is an essential contribution to the EU's efforts to develop a sustainable, low carbon, resource efficient and* *competitive economy. Such transition is the opportunity to transform our economy and generate new and sustainable competitive advantages for Europe"(COM (2015) 614, 2015, p. 2)*

Table 3. Actions and timetable of the EU Circular Economy Action Plan for Waste management

Actions	Timetable
Waste management	
Revised legislative proposal on waste	Dec 2015
Improved cooperation with member states for better implementation of EU waste legislation, and combat illicit shipment of end of life vehicles	2015 onwards
Stepping up enforcement of revised waste shipment regulation	2016 onwards
Promotion of industry-led voluntary certification of treatment facilities for key waste/recyclates streams	2018 onwards
Initiative on waste to energy in the framework of the Energy Union	2016
Identification and dissemination of good practices in waste collection systems	2016 onwards
Market for secondary raw materials	
Development of quality standards for secondary raw materials (in particular for plastics)	2016 onwards
Proposal for a revised fertilisers regulation	Early 2016
Proposed legislation setting minimum requirements for reused water for irrigation and groundwater recharge	2017
Promotion of safe and cost-effective water reuse, including guidance on the integration of water reuse in water planning and management, inclusion of best practices in relevant BREFs, and support to innovation (through the European innovation partnership and horizon 2020) and investments	2016–2017
Analysis and policy options to address the interface between chemicals, products and waste legislation, including how to reduce the presence and improve the tracking of chemicals of concern in products	2017
Measures to facilitate waste shipment across the EU, including electronic data exchange (and possibly other measures)	2016 onwards
Further development of the EU raw materials information system	2016 onwards
Construction and demolition	
Pre-demolition assessment guidelines for the construction sector	2017
Voluntary industry-wide recycling protocol for construction and demolition waste	2016
Core indicators for the assessment of the lifecycle environmental performance of a building, and incentives for their use	2017 onwards

Source: (Migliore et al., 2020)

Regarding waste, the CEAP focuses on principles and goals that should guide the EU's supporting actions in transition to circular economy:

- Product design. The Commissions incentives for a design approach that aims to make products more durable or easier to upgrade, repair, reuse or remanufacture. This means to help recycling companies to disassemble components and products to recover valuable materials and also to stimulate a better product design through differentiation of the financial contribution of producers under extended producer responsibility schemes based on the end-of-life costs of their products;
- Production processes. The Commission should stimulate the sustainable raw materials sourcing through partnership and trade, best practices in strategic industries, development policy, legislative proposals on waste to clarify rules to support industrial symbiosis practices.
- Consumption. The Commission should stimulate waste preventive actions and reuse of materials and components through the exchange of information, experience, and best practices and through providing of Cohesion Policy funding for projects at regional and local level. Support of the circular economy through promotion of sharing products or infrastructure, providing services rather than products and using of IT or digital platforms.
- Waste management. «The Commission is adopting provisions to promote greater use of economic instruments; general requirements for extended producer responsibility schemes; simplification and harmonization of definitions and calculation methods and will step up its work with Member States to improve waste management on the ground, including to avoid overcapacities in residual waste treatment» (COM (2015) 614, 2015).
- Markets for secondary raw materials and waste reuse. Development of the market for secondary raw materials is evaluated as a key condition for a circular economy development. The Commission should develop quality standards for secondary raw materials in different industries and improve rules on end-of-waste. It should be also easy to trade secondary raw materials across the EU borders, with use of electronic data exchange. Availability of data, tools and indicators is also a necessary condition for secondary raw materials market development. The Raw Materials Information System aims to improve the data availability on secondary materials.

Construction industry relevance:

In 2015 Circular Economy Action Plan, construction and demolition is mentioned as a priority area. In CEAP three actions, related to C&DW required for the achievement of a circular economy, were listed. As a response to these actions, three guidelines or framework documents have been developed (see Table 4):

Table 4. Implementation of the Circular Economy Action Plan in Construction industry

Action	Guidence/framework documents	Details
Pre-demolition assessment guidelines for construction sector	**EU Waste Audit Guideline:** pre-demolition guidelines to boost high-value recycling as well as voluntary recycling protocols aimed at improving quality and building confidence (European Commission, 2018).	The Guideline describes the waste audit process and elements to be included in it. The waste audit, to be organized by the owner of a building or infrastructure, should results in an inventory of materials and components arising from (future) demolition, deconstruction, or refurbishment projects, and provide options for their management and recovery.
Voluntary industry-wide recycling protocol for construction and demolition waste	**EU Construction and Demolition Waste Management Protocol:** aims to ensure recovery of valuable resources and adequate waste management in the construction and demolition sector (European Commission, 2016a).	Any demolition, renovation or construction project needs to be well planned and managed to reduce environmental and health impacts while providing important cost benefits. The Protocol lists following actions to increase confidence in the C&D waste management process and the trust in the quality of C&D recycled materials:
		a) Improved waste identification, source separation and collection;
		b) Improved waste logistics;
		c) Improved waste processing;
		d) Quality management;
		e) Appropriate policy and framework conditions.
Core indicators for the assessment of lifecycle environmental performance of a building, and incentives for their use	EU Level(s) – European reporting framework for sustainable buildings: aims to facilitate the assessment of the environmental performance of buildings (European Commission, 2019).	A tool for designing and constructing sustainable buildings. It is a voluntary reporting framework to improve the sustainability of buildings; it includes indicators reducing environmental impacts and for creating healthier and more comfortable spaces for occupants.

Source: (SWD (2019) 90, 2019; Wahlström et al., 2020)

3.3.2 The Waste Framework Directive 2008/98/EC amended 2018/851 (WFD)

Directive 2018/851 is the fundamental legislative document on waste at the European Union level, which is transposed into the national legislation of the EU's Member States by means of separate legal acts. Through this Directive the EU aims to remove the link between economic growth and the waste production. This Directive has modified the legal framework for waste. There is a requirement for Member States to prepare waste management plans considering the quantities, the type, the sources and the systems of waste collection (Directive (EU) 2018/851, 2018).

The Waste Framework Directive 2008/98 (WFD) provides common criteria and goals that are related to waste with waste management improvement aim. Directive 2008/98 frames also basis for the adaptation and development of circular economy, guiding actions at the political and operation levels. Through this Directive some basic principles for waste management and a legal framework for waste treating were established in the EU with the aim to protect the environment and human health, to prevent or reduce the waste generation, to reduce pressure on natural resources, to promote recovery and recycling techniques, to stimulate the transition to a circular economy and to provide the EU's long-term competitiveness. WFD:

- Specifies the basic definitions and concepts related to waste management, such as re-use, recovery, recycling, preparing to re-use (Directive 2008/98/EC, 2008, art. 3 amended by Directive 2018/851).
- Describes the 'waste hierarchy' in waste management (prevention, preparing for re-use, recycling, other recovery, e.g. energy recovery and disposal) (Directive 2008/98/EC, 2008, art. 4). This description represents common reference for the measures that should be taken by the Member States.

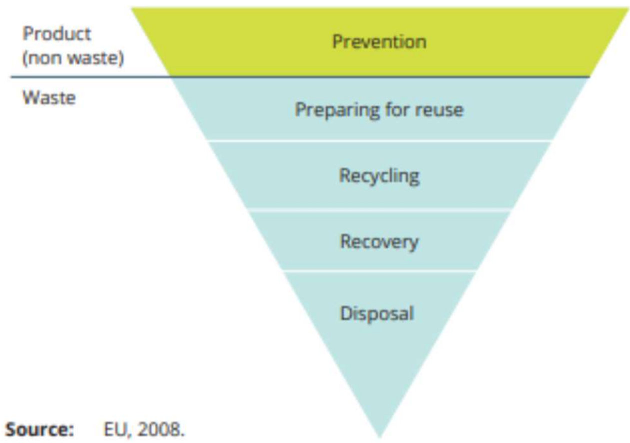

Figure 4. The waste hierarchy according to Waste Framework Directive 2008/98/EC.
Source: (Directive 2008/98/EC, 2008)

- Distinguishes between waste and by-product (D. 2008/98 art. 5 emended by D. 2018/851).
- Explains the 'end-of-waste' concept, which says that «certain specified waste shall cease to be waste ... when it has undergone a recovery, including recycling, operation and complies with specific criteria» (Directive 2008/98/EC, 2008, art. 6).

- Introduces the concept of ‘extended producer responsibility’ according to which «to strengthen the re-use and the prevention, recycling and other recovery of waste, Member States may take ... measures to ensure that ... producer of the product has extended producer responsibility. This may include an acceptance of returned products and of the waste that remains after those products have been used, as well as the subsequent management of the waste and financial responsibility for such activities» (Directive 2008/98/EC, 2008, art. 8). This measure can require providing publicly available information about product’s re-usability and recyclability.
- Introduces ‘re-use’ concept according to which Member States should take measures, «to promote the re-use of products and preparing for re-use activities, notably by encouraging the establishment and support of re-use and repair networks, the use of economic instruments, procurement criteria, quantitative objectives or other measures» (Directive 2008/98/EC, 2008, art. 11).
- Establishes the ‘polluter pays principle’ in accordance to which «The waste producer and the waste holder should manage the waste in a way that guarantees a high level of protection of the environment and human health». «the costs of waste management shall be borne by the original waste producer or by the current or previous waste holders» (Directive 2008/98/EC, 2008, art. 14).
- Establishes responsibility for waste management by specifying the necessary measures that Member States should take «to ensure that any original waste producer or other holder carries out the treatment of waste himself or has the treatment handled by a dealer or an establishment or undertaking which carries out waste treatment operations or arranged by a private or public waste collector» (Directive 2008/98/EC, 2008, art. 15).
- Requires adaptation of waste management plans and waste prevention programs from Member States (Directive 2008/98/EC, 2008; Migliore et al., 2020).

Construction industry relevance:

Waste Framework Directive 2008/98/EC amended 2018/851 (WFD) sets clear targets for the waste management and requirements for waste management and recycling, taking in consideration quantitative recovery targets for Construction and Demolition Waste (C&DW), to be achieved by 2020. The end-of-waste concept defines criteria to identify when a waste cases to be a waste and become a secondary material or product. According to WFD *“Member States shall take measures to promote selective demolition in order to enable removal and safe handling of hazardous substances and facilitate reuse and high-quality recycling by selective* *removal of materials, and to ensure the establishment of sorting systems for C&DW at least for wood, mineral fractions (concrete, bricks, tiles and ceramics, stones), metal, glass, plastic and plaster"* (Directive 2008/98/EC, 2008). In addition, by 31 December 2024, the Commission should review setting preparing-for-reuse and recycling targets for C&DW and material-specific fractions of it.

According to Directive 2008/98/EC, Article 8 on Extended producer responsibility, Member states should take measures to stimulate *«production and marketing of products that are suitable for multiple use, that are technically durable and that are, after having become waste, suitable for proper and safe recovery and environmentally compatible disposal»* (Directive 2008/98/EC, 2008) This can be applied to design and production stages in construction life cycle.

In this section of the paper, legal framework on circular economy implementation and waste management with relevance to construction sector was studied. We can see that development of the market for secondary raw materials is evaluated as a key condition for a circular economy development in CEAP. We also see that WFD requires promotion of the re-use of products and preparing for re-use activities among European countries. Thus, one can see that reuse is seen as a tool for transition to circular economy with economic, social, and environmental benefits. In the next section, we will see how circular economy can contribute to construction sector.

3.4 Construction and Demolition Waste and Circular Economy

In this section, actions that should be taken on every phase of a building lifespan during circular economy implementation will be presented.

As it was already mentioned above, in construction environment raw materials remain in their life cycle as long as possible, with preserving value of those materials on the highest possible level through efficient and smart use. This would mean that construction elements and buildings are designed to be easy to adapt, easy to dismantle and unlikely to be ever demolished. Construction materials and components would be quickly and efficiently recovered, this would result in significant reduction of waste generation. Hazardous materials (such as asbestos) would be eliminated from the material cycle.

To implement this, a new approach, which will involve all actors in the value chain is needed, with different sectors working together. In circular economy, C&DW management is viewed from a systemic perspective, where intervention to be taken in all parts of the system and all

stages of buildings' lifecycles. Circular economy inspires actions to be taken on early stages of a building's lifecycle, those actions can affect the C&DW management in a profound way.
For example, circular economy actions in the production and design of a structure phase can impact the recovery potential of materials streams from its construction. The selection of high-quality and durable construction materials would increase a building's lifetime and contribute to waste prevention. "*Overall, circular economy thinking views waste management systems as the result of decisions a taken in earlier stages in its lifecycle*"(Wahlström et al., 2020).
Typical examples of key actions for circular economy implementation in a building's lifecycle were divided on different phases and collected by (Adams, Osmani, Thorpe, & Hobbs, 2017) from literature and as a result following list of actions emerged in (Wahlström et al., 2020) which was further elaborated with focus of waste.

List of actions for circular economy implementation at every stage of the construction environment:

1. Material production phase

- *"the building materials are renewable;*
- *the production processes have low environmental impacts;*
- *the materials have a high recycled content;*
- *the materials are highly durability and therefore have a long lifetime;*
- *the building materials are not hazardous"* (Wahlström et al., 2020).

2. Design phase

Better design is a key to scaling up reuse and recycling, it also helps to make buildings and construction products easier to repair and more durable, and by this saving precious resources. In circular design, resource use is weighted against a building's needs and functionality and considers deconstruction scenarios. The Level(s) (European Commission, 2019) framework supports efforts for optimization of building design and their operation and minimizes gaps that take place between design and actual performance.

Possible action includes:

- *"modular and easy-to-disassemble buildings;*
- *durable, flexible, repairable, upgradable and adaptable structures prolonging their lifetime;*
- *reduce the amount of materials used through avoiding over specification of materials and using higher-strength materials;*
- *integrate nature-based infrastructure (such as green roofs)"* (Wahlström et al., 2020).

3. Construction phase

- *"avoid material surpluses through using tailor-made construction materials;*

- create a material passport during construction;

- additive manufacturing (such as 3D printing of concrete);

- selective sorting of construction waste;

- give away unwanted or surplus stock from the construction;

- building information management (BIM) helps create and maintain value through the entire lifecycle of a building and its parts" (Wahlström et al., 2020).

4. Use phase

- "update building information models and its material passport during use;

- performance-based contracts for the built environment;

- extended producer responsibility (Hilton, 2018);

- increase use intensity of buildings through, for instance, flexible functionality for different users at different times of the day, sharing work or living spaces;

- lifetime extension by the advanced rehabilitation, repairing and strengthening and retrofitting of structures;

- maintenance of buildings and infrastructure" (Wahlström et al., 2020).

5. End of life phase

Currently arising the material streams from renovation and demolition work are an inheritance from the linear economy operation. In most cases, those materials are not easy to disassemble for instance glued materials and spray insulation, do not allow for reuse and/or high-grade recycling. For these materials, it is very important to establish appropriate demolition practices, processing methods and logistics to facilitate close material loops as much as possible. The EU Construction and Demolition Waste Management Protocol (European Commission, 2016a) describes the actions to be taken at the end-of-life stage:

- "*qualitative pre-demolition material auditing and waste management planning;*

- decontamination of the built environment: removal and safe handling of hazardous materials;

- at source sorting of high-grade material fractions;

- monitoring demolition and renovation work to assure (trust in) material quality for recycling and reuse;

- selective demolition;

- preparing construction materials for reuse and recycling;

- increase traceability, quality assessment and certification of C&DW streams;

- improved sorting systems for materials that cannot be collected separately during demolition" (Wahlström et al., 2020).

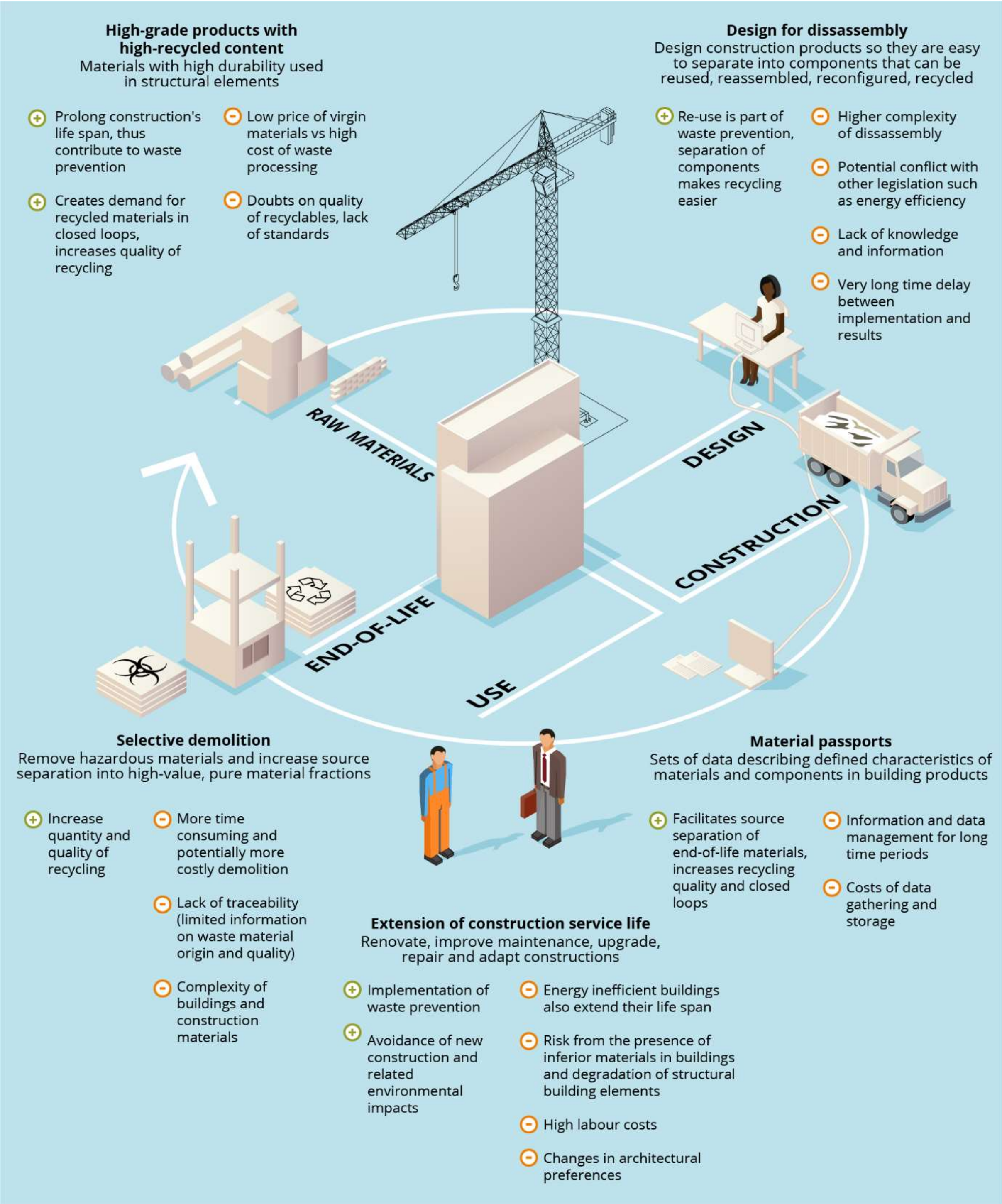

Figure 5: Implementation of Circular Economy principles in Construction sector

Source: (EEA, 2020)

All those actions, presented above, can lead to improved C&DW management in the long-term perspective. The introduction of reuse solutions on the design and construction stages that aim the prolongation of building’s lifespan will also provide significant environmental benefits in

C&DW management by preventing and lowering amount of waste generation. However, only a part of the suggested actions will improve the C&DW management in the short term.

3.5 Future construction sector in circular economy environment

In this section, future vision of construction sector based on Arup (2016) report will be presented. This report focuses on the built environment level that offers the opportunity to increase efficiencies and reduce costs and environmental impact. Some examples of circular models to improve the ecosystem and value chain for following stages of construction life cycle: design, construction, operation, renewal, and repurposing of buildings will be presented. In addition, requirement for cooperation between stakeholders and sharing of information on characteristics of components, structures and materials will be highlighted (Wahlström et al., 2020).

"In the built environment, it's all about maximizing utility of resources — extending product life or providing a proper end-of-life recovery." (Nick Cliffe, Innovate UK in Arup, 2016).

At the building level implementation of circular economy in the construction and property sector can be illustrated with the commercial property example (see Fig. 6).

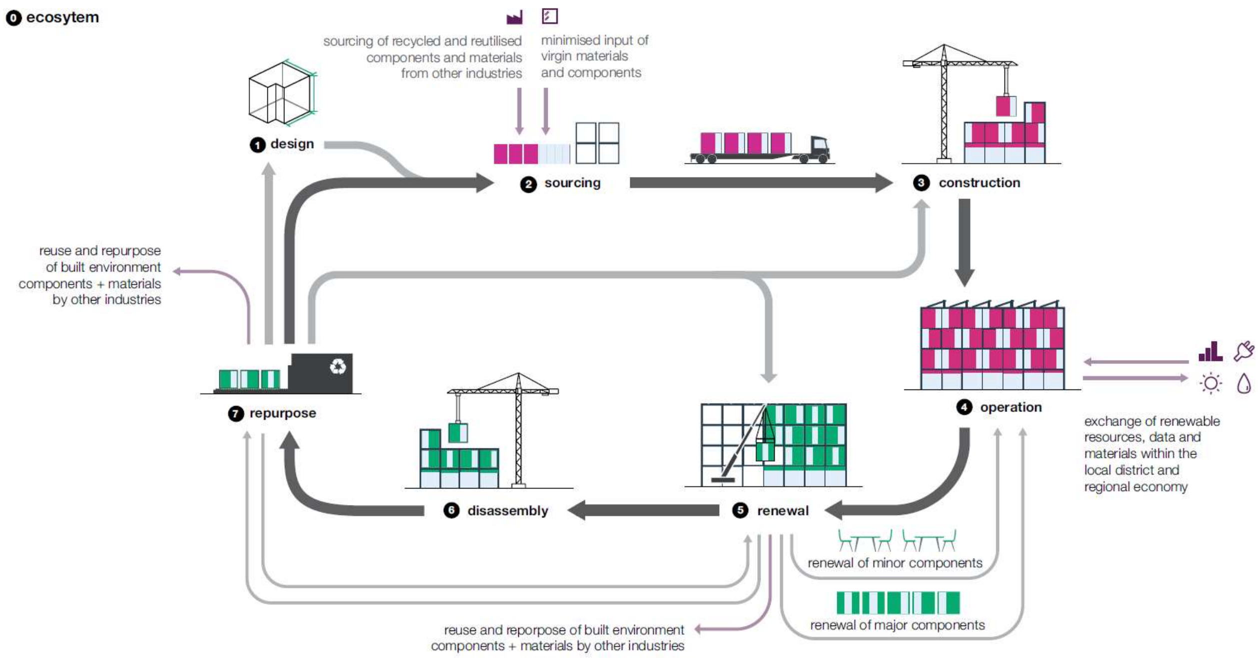

Figure 6: Implementation of Circular Economy Principles in Commercial Property
Source: (Arup, 2016)

0. Ecosystem

In a circular economy, design of buildings will be performed considering a whole lifecycle of it. To do this, different stakeholders will collaborate on cloud-based BIM models with analytical software. These models will be able to clearly visualize all externalities of a proposal. Moreover, policy and incentives will motivate clients to focus on full lifecycle contracts from design phase to operation and disassembly and encourage them to achieve holistic lifecycle certifications and awards. Structures and components will be in most cases leased rather than purchased. Contracts based on performance will replace payments for individual fittings or materials by payments for services like lighting. Circularity will be incorporated in all parts of an ecosystem. This will lead to higher flexibility, interchangeability, and high customizability of individual assets, and will increase environmental experience of users. Design decisions like optimization of reuse and disassembly from the beginning of the program will have implication for operation phase, renewal and repurposing of construction or building and components. In the circular economy model, constructions of a building will be incorporated in the resource and reuse cycles of other industries. On the operational phase the building will use renewable sources of energy and locally available streams of used materials. This will lead to higher resilience of the building and lower risks for investment. 24/7 flexible use with high level of occupation will be applied during the day and night to increase efficiency (Arup, 2016).

1. Design

In circular economy model, open-source design will be a standard practice, where designers, architects and engineers will collaborate, share their designs and build based on each other’s work. The way of thinking of building designers will change in a way where buildings and structures will be retrofitted and reused if possible before designing of new structures. Operation and performance of buildings will be incorporated into design process from the beginning, to include principles of energy efficiency like passive design and reduced externalities (Arup, 2016) .

2. Sourcing

Because of resources scarcity, in future the extraction of materials can be dramatically curtailed. Therefore, key components of design in circular construction environment will be modularity and adaptability. This means that buildings will be constructed from durable, flexible, reused, and reusable components and materials. Non-standardized components and materials, which remained as a long-term linear economy legacy will be reused and repurposed as much as possible. As an example, old in-situ components could be turned into other building modules (Arup, 2016).

3. **Construction**

In a circular world, the word construction will be used with meaning of assembly. The physical production of bespoke elements, like steel components or concrete casts, may no longer be standard practice because the construction industry moves to increased flexibility. Though, 3D printing with the introduction of substrates and resins produced from reusable or renewable materials could challenge flexibility trend. Prefabrication and off-site manufacturing will decrease waste generation on construction sites (Arup, 2016).

4. **Operation**

All structures and buildings will be designed based on high efficiency standards, with minimal externalities and environmental impacts. These will include structures which will have internal circular cycles of resource like water capture and filtering. Even more, buildings will become net producers of energy. Buildings will have battery storage and fit/out components with low impact such as led lights and strategies which exclude wastage of materials and energy. Building users and tenants will lease services and components, paying for services instead of individual fittings. The components and structures will be managed regularly applying preventative maintenance techniques. Key component of these techniques is low-energy and low-cost sensor technology which will help to reduce costs and disruption and increase the effective and useful life of the building and its fittings. Principles of sharing and flexible use will increase occupancy rates.

5. **Renewal**

The functions of buildings and requirements to them are constantly changing, but today they are rigid and static by design. In future circular world, buildings will represent dynamic platforms making possible greater flexibility and adaptation. For example, designs will provide easy access to building services or incorporate reconfigurable and demountable façade systems. This will decrease the time and cost needed for renewal and exclude waste generation and other outputs. Policies and industry standards will increase interchangeability of components from different providers and manufacturers (Arup, 2016).

6. **Disassembly**

In a circular world demolishing will be minimized and circular design approaches will construct new buildings allowing for change and disassembly. Lifecycle BIM models will enable stakeholders to easily disassemble buildings and expand, contract, or redesign them using the same components. Structural parts can be transported by standard vehicles and in standard containers. Thus, buildings in circular economy will be highly flexible, mobile and versatile and will have longer and more efficient lifetime (Arup, 2016).

7. **Repurpose**

The circular construction environment will encourage maximal use of materials and components. This will be done by circulation of materials and components between projects and buildings and by maintaining them at the highest value and performance. If components and materials will no longer be appropriate for use in the same functionality, they will be recycled and remanufactured into other parts or products, possibly with lower value, and be redirected to other industry. Every component and material part will be mindfully tracked through its lifecycle, and all data will be recorded in BIM lifecycle models. Established second-use strategies and value networks will secure adequate use of all materials and components in other industries with minimal loss of value and secure numerous repurpose cycles (Arup, 2016).
From the examples above one can see that circular economy potential to change the ecosystem and value chain for different phases of building's lifecycle, such as design, construction, operation, renewal and repurpose, is huge. It requires collaboration and information exchange between different stakeholders and focus of investors and designers on longer-term view with careful mapping of the past, current, and future construction material, and component use. It also requires incentives and tools which make possible for investors to receive a financial return on those decisions that affect not only the leasing and selling of spaces and properties, but also their repurpose and end-of-life usage. Moreover, new circular business models are needed to increase effective asset use and encourage more use of renewable components, materials and resources (Arup, 2016).

8. **Digitalization to support the transition to circular economy**

Digitalization can lead to reduction of costs at all stages of the construction value chain. According to EU BIM Task Group (2017), it can be used to:

- manage material flows and track complex supply chains – material/product traceability, use of BIM and data storage from the sensors use;
- design new (3D) products minimizing material use, and increasing productivity;
- optimize sharing business models;
- automate materials handling and maintenance in construction – for instance, use of radio-frequency identification (RFID) sensors and tags in material detection and handling, and robot waste sorting (EU BIM Task Group, 2017).

The implementation of BIM provides new possibilities for the future construction processes, especially for material handling and waste management.
Currently, changes in construction environment are in the most cases focused on energy efficiency. If the material impact is not considered, action of circular economy in the future can

be strongly hampered by, for instance, different materials glued to each other or non-dismountable composites from materials which require different recycling options (Wahlström et al., 2020).

3.6 Challenges on the way to circular economy actions in construction sector

The list of circular economy actions on different phases of building's life cycle and future vision of construction sector in circular economy environment, presented in previous sections, shows the potential for increased circular consideration of waste policy objectives. Nevertheless, in "Construction and Demolition Waste: challenges and opportunities in a circular economy" report by Wahlström et al. (2020), main barriers that hinder the full-scale implementation of those actions were identified and will be presented in this section. According to this report there are economic, concern quality control, and the delay in seeing measurable results from circular economy implementation, barriers. Poor or inadequate quality, and continuity of supply that influence the use of recovered materials in new components and products. Moreover, the lack of standards, experience, and guidance to guaranty the quality of reusable products hinder reuse. There are also many challenges that are related to the potential content of hazardous substances, contaminants which are prohibited today but were permittable in the past when the products were manufactured. In addition, challenges related to data transfer along the value chain reduce trust in the quality of recycled/reclaimed materials and components. And for some materials, technological innovations, and new business models, are needed for more high-grade recycling and reuse. (Wahlström et al., 2020). In Table 5 below, which is adopted from Wahlström et al. (2020) report, all those challenges are presented with specification, examples, and possible solutions. This table will be further used as a basis for analysis of collected through SWOT-analysis data in Chapter 5.

Table 5. Challenges in implementation of circular principles in the management of construction and demolition waste.

Challenge	**Specification**	**Example of construction waste**	**Examples of potential solutions for removing of barriers**
Quality of waste	Heterogeneity (complex materials), too high content of impurities. Hazardous substances Lack of traceability. Material degradation during use.	Multicomponent products – sandwich constructions.	Less complex products. Pre-demolition audits with follow-up checks on the removal of contaminants prior to demolition. Introduction of sensors in products for securing traceability. Development of tools for detecting product degradation/ageing.
Technological challenge	Processing needs for new rejects. Complex products may require multiple processing steps before recycling, increasing total cost.	Prefabricated elements, fine fractions in concrete waste (cement), plastic waste, insulation waste.	New technological development/new business models. Design for disassembly.
Economics	Low price of virgin materials. Increase of cost due to more work intensive, higher energy needs. Lack of new business models – sharing of apparatus, facilities, etc.	Concrete waste, wood waste.	Governmental measures – landfill bans, taxes, green public procurement supporting recycling. Sharing of process equipment.
Traceability	Lack of standards and tools. Quality systems for complex materials.	Concrete waste, reusable components/structures.	Standardization and commitments between stakeholders.
Responsibilities	Role of different actors not clear. Extended product responsibility not applicable for construction products with long lifespan.	Products containing parts from several manufacturers.	Role of building owner in construction phase.
Technical requirements	Potential overspecification of virgin materials, standards not suitable for recyclables.	Metal/wooden/concrete structural elements.	Development of new standards.
Legal issues	Difficulties for CE-marking (scope of harmonized product standards not covering waste related materials)	Metal/wooden/concrete structural elements.	Standardisation.
Environmental aspects	Emissions from several processes can increase impacts. Lack of assessment tools for estimation of material or landfill savings during whole lifetime – focus mainly on greenhouse gas emissions. Environmental impacts often case specific – local conditions, availability of alternative materials, transport. Risks for hazardous substances.	All waste types.	Develop further life cycle analysis indicators for the saving of natural resources – not only focus on greenhouse gases. Promotion of local solutions where materials are not transported.

Source: (Wahlström et al., 2020)

Besides the economic factors, the quality of construction materials and products play an important role in considering of the uptake of circular economy solutions. Lack of available information and documentation on the origins of waste (used materials and products) and data on the composition of materials and products can cause doubts about quality. Standardization plays a significant role in the assessment of secondary materials performance in products replacing raw materials and in the design of construction materials and products. Standardization is the basis for certification of products used in trade and business (Wahlström et al., 2020). Thus, it is important to understand which challenges can arise when circular economy actions should be taken in construction sector.

3.7 Reuse

3.7.1 Reuse as a bridge between waste prevention and the circular economy

From sections above we can see that materials reuse is an important element in circular economy transition process in construction sector. It is mentioned frequently in legal framework as waste prevention action and in actions for circular transition especially on design and end-of-life stages. In this section subject of reuse as a measure for transition of the construction sector to circular economy, namely effectivization of resources use and waste prevention will be considered in more details.

According to EEA (2018) report, reuse and related waste prevention activities in the EEA member countries have environmental and socio-economic benefits. *"Reusing products and components at the end of their use phase can reduce waste generation and potentially save natural resources by extending the use phase of products at the same time. Reuse, as well as preparation for reuse, can thus provide a link between the waste hierarchy of the Waste Framework Directive, on the one hand, and the European Commission's Circular Economy Action Plan, on the other"(EEA, 2018)*

3.7.2 Waste Prevention and Reuse

From the perspective of waste prevention and generation of secondary products and materials, circular economy is certainly boosting a more efficient use of material resources, opening new markets, developing new skills and business. Considering Construction and Demolition Waste (C&DW), namely the subject of the waste hierarchy (Directive 2008/98/EC, 2008), that reflects priority order in waste prevention and management, reuse as waste preventive measure deserve some further reflection with focus on different impacts of reuse and recycling.

EU legislation does not point out some specific targets for reuse and recycling, and much of waste streams, that was diverted from landfill, has been recycling in a way that generate mainly lower value products (downcycling) (Talamo, 2020).

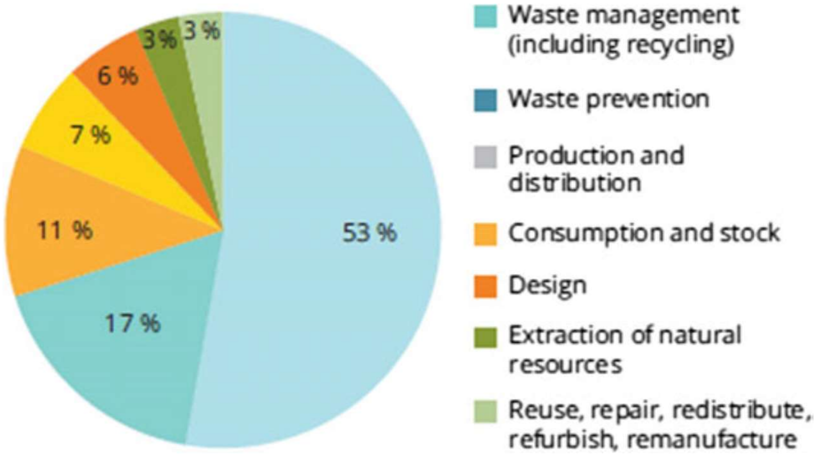

Figure 7.: National policy approaches to closing material loops from "More from less—material resource efficiency in Europe" study of European Environment Agency.
Source: (EEA, 2016)

On Figure 7, above, we can see that circular economy approaches in the EU are predominantly focused on the waste management stage, and only a few countries consider the early stages in the product life cycle such as reuse, repair, redistribute, refurbish, remanufacture as main instruments for closing material loops (EEA, 2016).

According to Rose and Stegemann (2018), it is dangerous to assume that mitigation of the impact of C&DW has been successful as recycling rates rise. *"A first problem is that these data are based on whether waste is sent to recycling companies, rather than whether it is recycled. Secondly, the impacts of transportation and recycling processes can be considerable. Thirdly, recycling processes can be highly wasteful"* (Rose & Stegemann, 2018).

Hobbs and Adams (2017), say that reuse should be considered as a priority in comparison to recycling. They underline that reuse usually requires minimal processing before replication of products or components in a similar application. Recycling, in its turn, usually requires breaking down waste into a homogenous material for a lower value application or used as replacement feedstock for manufactured components. *"A common misunderstanding lies between the realms of reuse and recycling of old buildings; they are often considered together when they are actually competing choices for the continuing use of resources"* (Hobbs & Adams, 2017).

3.7.3 Challenges to increasing reuse

According to EEA (2018) report: "Waste prevention in Europe—policies, status and trends in reuse in 2017", there are some challenges that affect increase of reuse scope. Those challenges can vary depending on national and local circumstances and can include following:

- **Mismatch of supply and demand** – in terms of quantity and quality. This means that if heavy materials or constructions need to be transported over long distance to reach their markets, this can lead to significantly increased costs and environmental impact.
- **Insufficient time for deconstruction and careful packing up of reusable items** – longer time that is needed for deconstruction can be unappealing in cases where extra costs are incurred through having a building (such as local property taxes) or through loss of revenue on a replacement building related to extended scheduling of works. Time can be also limited because of planning permission expiration (Hobbs & Adams, 2017).
- **Lack of facilities locally** – many countries in the EU have a good reclamation facility spread, nevertheless space is expensive and limited in highly built up areas. This fact can cause a discrepancy between the location of the stocks of reclaimed for reuse items and the market where such items are demanded. The third-party costs will be added to the price of items, this can reduce the attractiveness of reclaimed components and products compared to new. This can play decisive role when matched against possible risks related to reuse.
- **Unwillingness to use products without tested performance certification** is one of the biggest barriers to reuse, especially in a structural capacity. In most of the cases, information on where the product has come from and how long it has been used, is very restricted. This means that to the potential reuse applications the 'worst case scenario' is applied. Testing of product performance can be expensive and require annihilation of samples to mitigate risks of further use. These costs will be added to the purchasing price of the product and this may override savings for reuse (Hobbs & Adams, 2017).
- **Health and safety risks of manual deconstruction** of buildings are a decisive factor for the move to mechanical techniques for demolition. There is a way to mitigate those risks through improved data on building design and composition. Unfortunately, this information is usually not available.
- **Building technology** is a combination of traditional and rapidly changing techniques. Both techniques can cause challenges in future reuse, such as use of cement mortar in brick and block construction, trough to rapid fix, prefabricated panelized systems that are multi-material components.
- **Products' and materials' value** can be both an opportunity and a barrier. For cheap products and materials, the incentive to reuse, considering the cost of careful remove, can be low or negative (Hobbs & Adams, 2017).

We can see that there are many barriers, that were identified in EEA (2018) report, on the way to construction materials reuse's scaling up, but the main challenge is to assess all those barriers and to find ways for overcoming them in the forthcoming and existing circumstances of construction environment (Hobbs & Adams, 2017).

3.7.4 Opportunities for and benefits from scaling up construction materials reuse

There is a number of opportunities to increase reuse of construction materials, from all stages of the supply chain, including design, production, construction, refurbishment, and demolition. Some high-level strategies for reuse ate presented below:

- Reuse of offcuts and surplus materials both inside the project and between projects
- Design of materials and products suitable for deconstruction and adaptability
- Pre-demolition audits, on-site materials' sorting, and separate collection (Hobbs & Adams, 2017)
- Waste exchanges and industrial symbiosis
- Standards, certification and testing of products to improve reuse
- Projects' planning including procurement practices that promote use of reclaimed products and materials
- The community sector involvement to maximize local benefits (Hobbs & Adams, 2017)

3.8 Current situation of construction sector

3.8.1 Construction sector's current situation in the EU

In this part of the paper, the construction sector's current stage on the transition way to circular economy will be evaluated based on available reports and statistics sources.
The construction sector consume resources and produce waste (see Figure 8) more than other industry sectors in Europe: *"Economically, construction is one of Europe's largest industrial sectors, with an annual turnover exceeding 1200 billion Euros, and activities that account for 10.4% of the EU GDP. 7.2% of the EU workforce is directly in the building and construction sector. The aggregated impacts of housing and infrastructure account for around 15–30% of all environmental pressures of European consumption. Housing and infrastructure contribute approximately 2.5tons of CO2 equivalent of greenhouse gasses per capita per year. 40% of these GHG emissions are directly associated with heating and hot water for private households.*

The construction of buildings and other infrastructures contributes another 30% of the total emissions" "*By improving resource efficiency in constructing and use of infrastructure and buildings, the EU can influence 42% of its final energy consumption, about 35% of its greenhouse gas emissions and more than 50% of all extracted materials, and save up to 30% water.*"(SEC (2011) 1067, 2011).

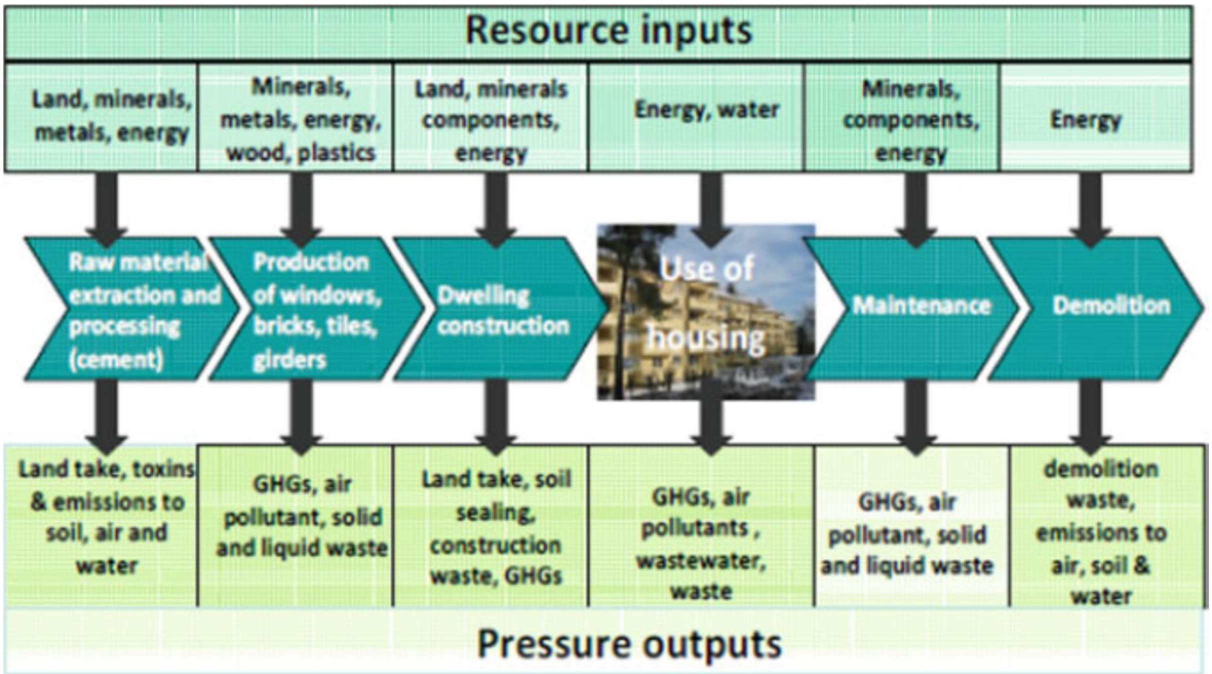

Figure 8.: The resources used along the value chain of construction.
Source: (SEC (2011) 1067, 2011)

3.8.2 Construction and demolition waste treatment in Norway in comparison to other EEA countries

According to the European Construction Observation: *"One of the most resource- and waste-intensive economic activities is construction. The construction sector produced 923 million tons of waste in 2016, which in terms of volume is the largest waste stream in the EU, representing 35% of all waste generated (see Figure. 9). Construction and demolition waste (C&DW) refer to the waste generated from general construction activities and includes concrete, bricks, gypsum, wood, glass, metal, plastic, solvents, asbestos and excavated soil. The recycling and reuse of C&DW components has high potential in reducing construction costs and negative environmental impacts, related to the extraction, processing and production of construction materials" (European Construction Sector Observatory, 2019, p. 3)*

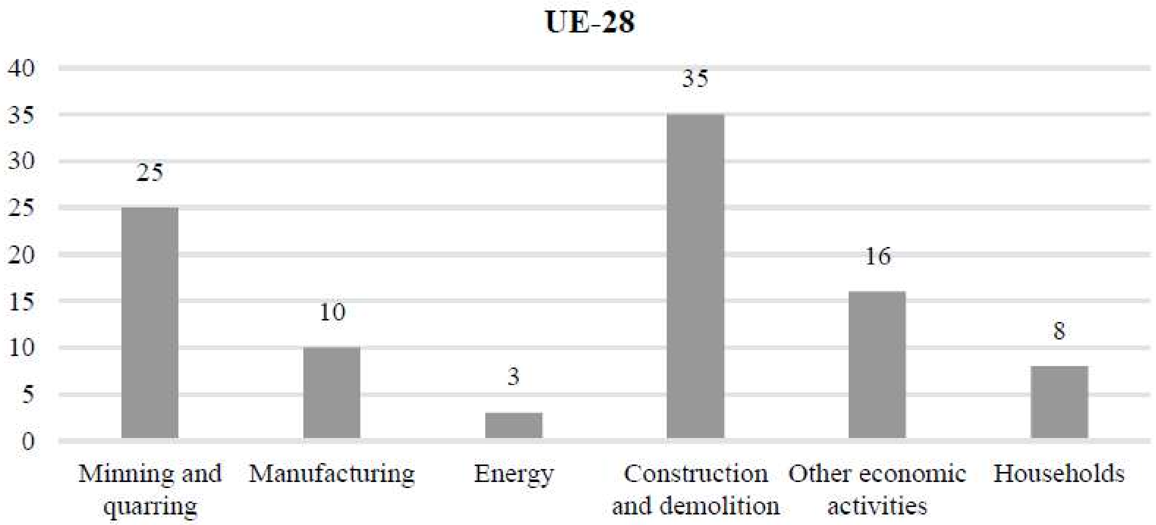

Figure 9.: Waste generation by economic activities and households, 2016, %.

Source: (Eurostat, 2020)

On Figure 9, one can see that the biggest amount of waste in Europe is generated by construction and demolition activities.

On Figure 10 below, one can see that variation in amount of waste generation between different countries is significant (Wahlström et al., 2020).

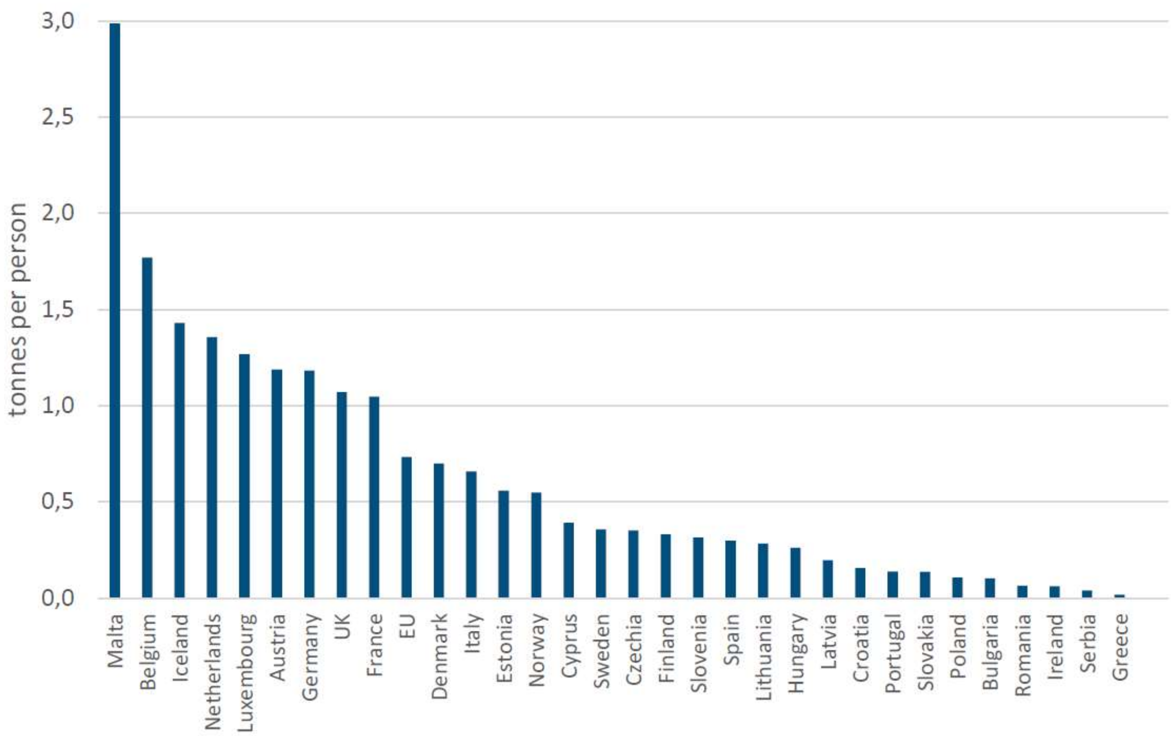

Figure 10. Generation of construction and demolition waste, EEA, 2016, tons per person.

Source: (Eurostat, 2020)

On Figure 10, one can see that in Norway amount of generated waste per person is 0,6 tons, which is in comparison with other countries not highest as in Malta 3,0 tons per person but still high in comparison with Greece for instance.

The analysis of statistics reliability Bio by Delotte (2017) showed that quality of registered data is poor in many European countries and need to be improved. Even in best performing countries there are uncertainties related to the C&DW data (Bio by Deloitte, 2017).

According to Eurostat (2019) the average recovery rate of C&DW in the EU was 89% in 2016 (Eurostat, 2019).

Eurostat define the recovery rate as *"the amount of C&DW that is prepared for reuse, recycled or subject to material recovery, including backfilling, divided by the C%DW treated" (Eurostat, 2019).* Figure 10 below, describes the recovery rate of non-hazardous mineral waste from construction and demolition in different European countries in 2016. This data is based on mineral waste from construction and demolition because no data are available on the treatment of other C&DW in Eurostat. In addition, Eurostat data does not include data on reuse of construction components or materials (Wahlström et al., 2020). The recovery rate of non-hazardous mineral waste is generally high in EU countries. Most countries already met the waste Framework Directive (WFD) target of, by 2020, *"preparing for reuse, recycling, or other material recovery, including backfilling operations, 70 per cent by weight of non-hazardous C&DW".* Such countries as Luxembourg, Malta, and the Netherlands reported 100% recovery rates in 2016. Even though, there are some uncertainties related to reporting on treatment of C&DW by EU Member States (COM(2018) 656, 2018; Wahlström et al., 2020).

C&DW recycling often means using materials from construction and demolition, for example, as base material in road building. The evidences show that the construction sector hardly uses any secondary materials. For example, in the Netherlands, secondary materials only represent 3-4% of all materials used in new building projects. Thus, despite high rates of recycling, the C&DW recycling is largely downcycling (Wahlström et al., 2020).

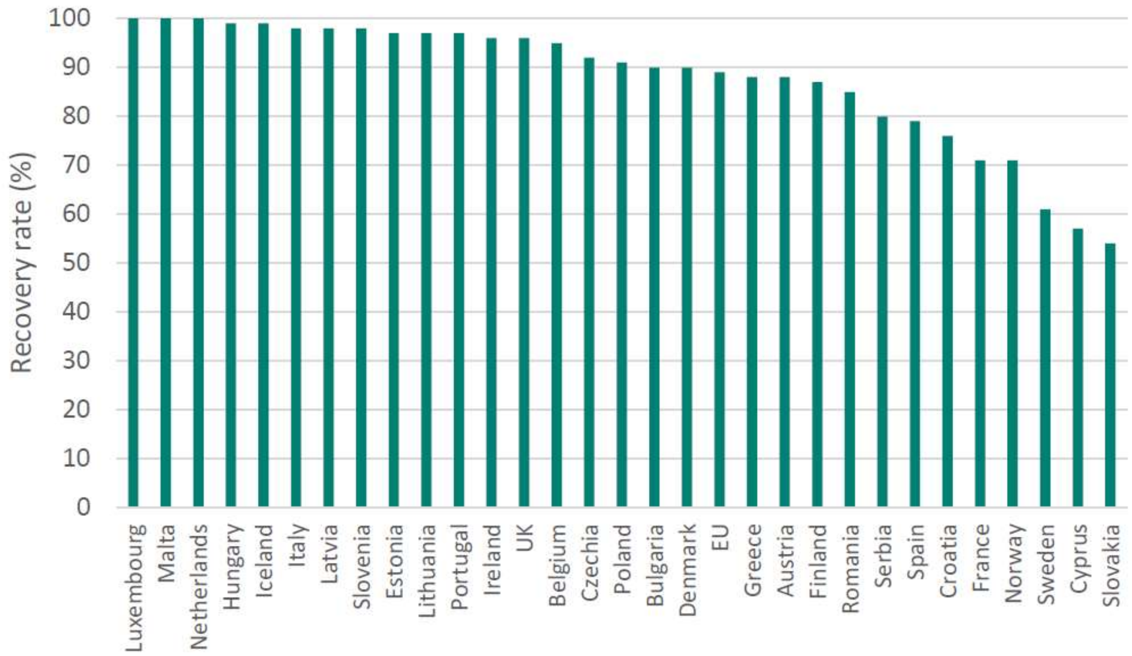

Figure 11. Recovery rate of non-hazardous mineral construction and demolition waste, EEA, 2016, %. Source: EWC-Stat 12.1 (Eurostat, 2019).

On Figure 11, one can see that recovery rate of waste in Norway constitutes 70%, which means that Norway as many other European countries managed to meet WFD target of 70% material recovery by weight of non-hazardous C&DW, by 2020, but at the same time this is almost the lowest recovery rate in comparison to other European countries (except Sweden, Cyprus, and Slovakia).

The waste hierarchy ranks options of waste management to their sustainability. The top priority is on waste prevention, then follow recycling, energy recovery and disposal, for instance by landfilling. Figure 12 below, shows different treatment methods percentages of C&DW mineral waste in 2016 (recycling, backfilling, energy recovery, incineration without energy recovery, landfilling) (Eurostat, 2019; Wahlström et al., 2020).

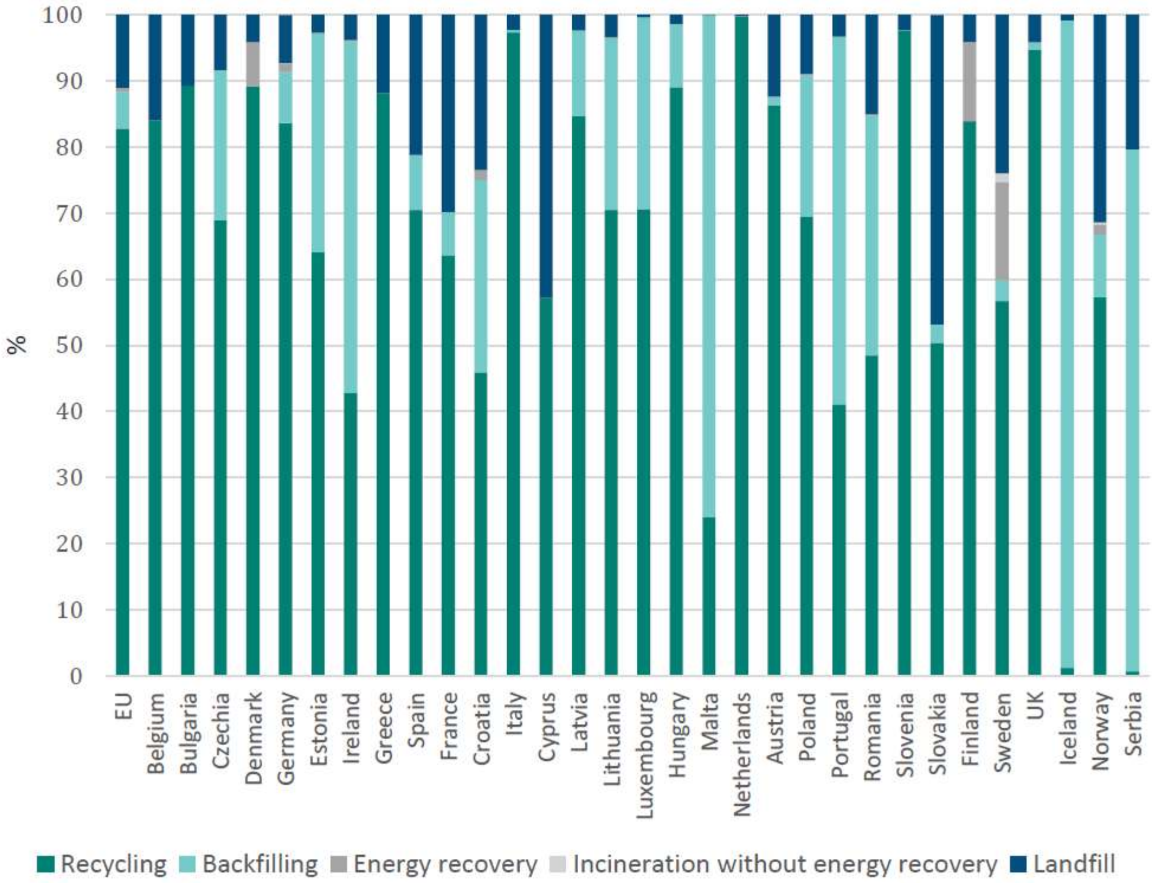

Figure 12. Treatment of mineral waste from construction and demolition, EEA, 2016, %.
Source: (Eurostat, 2019)

On Figure 12, one can see that among waste management options in Norway, recycling is prioritized and constitutes approximately 57% of total amount of waste treatment. Landfill, nonetheless, is on lowest rank in waste management hierarchy and constitute more than 30% of total waste management in Norway. In addition, in comparison to other European countries, Norway has almost the highest rate of waste landfilling (except Cyprus and Slovakia).

This section of the paper showed that the average of waste recovery rate in Europe is high (89% in average) and that almost all counties managed to meet 70% recovery target by 2020, including Norway. At the same time, one can see that data on materials reuse is not available from Eurostat. Even if rate of recycling is high in Europe, evidences show that there is very low rate of secondary materials and components reuse in construction sector. This means that the C&DW recycling is largely downcycling.

Regarding current stage of waste treatment in Norway, from the figures above we can see that in comparison to other European countries Norway is still behind with prioritizing recycling instead of prevention of construction waste generation through reuse and with almost the highest rate of landfill.

3.9 Legal framework for construction sector in Norway and its relevance to reuse

Circular economy is on the agenda in Norway. In the light of initiatives such as the EU Waste Framework Directive the topic of reuse of waste generated in construction industry found out in high political focus. Reuse of construction materials and components can lead to potentially large environmental benefits. In this section, we will look on the purpose of the construction legislation/regulations and on its relevance to reused products and materials.

3.9.1 Pollution of the outdoor environment (Forurensningsloven)

Purpose:

"The Pollution Control Act" represents a central part of the legal basis to which reuse of construction materials must be related to. "The purpose of this Act is to protect the outdoor environment against pollution and to reduce existing pollution, to reduce the quantity of waste and to promote better waste management. The Act shall ensure that the quality of the environment is satisfactory, so that pollution and waste do not result in damage to human health or adversely affect welfare, or damage the productivity of the natural environment and its capacity for self-renewal" (Forurensningsloven, 2019).

Relevance to reuse of construction materials and products?

This Act, § 2 (Guidelines), section 4 states that waste should be managed in a way to minimize damage and nuisance. "Waste should be recovered, preferably by being prepared for recycling or reuse, excepting those cases when recycling is not justified based on environmental, natural resources and economic considerations and factors" (Forurensningsloven, 2019). This formulation was included in the text of this Act in 2016. It shows that the principles of waste hierarchy, where reuse of materials should be prioritized against energy recovery, were incorporated into the law very recently. When definition of something has been changed, the low provides the guidelines for handling with this. The Pollution Control Act's § 27 defines waste as: "Waste means movable objects or substances which someone has discarded, intends to discard or is obligated to discard. Waste water and exhaust gases are not considered to be waste" (Forurensningsloven, 2019). In 2016 formulation in § 27 has been changed in a way it also explains how waste can cease to be waste: Movable objects or substances that have become waste can cease to be waste when they at least:

1. "have undergone recovery,

2. are used for specific purposes,
3. can be sold on the market or are subjects to demand,
4. meets the technical requirements that follows from the relevant application area and any product requirements and standards, and
5. do not entail a significantly higher risk of health damage or environmental disturbance than similar objects and substances that could otherwise be used" (Forurensningsloven, 2019).

Recovery means here: "any measure where the main result is that waste going to benefit by replacing materials that would otherwise have been used, or that waste has been prepared for this" (Forurensningsloven, 2019). The purpose of these amendments is to ensure that the law will not create obstacles to reuse of objects and substances. Though, for instance, bricks will cease to be waste when they undergone a recovery process, it is important that this process held in correspondence with the provisions of the Pollution Control Act. This means that residuals of paint, plaster and mortar that contain toxins should be separated from bricks in a proper manner (Asplan Viak, 2018).

3.9.2 Waste regulations (Avfallsforskriften)

Regulation on the recovery and treatment of waste (Waste Regulations) designed to explain how different types of waste must be treated. In this regulation one can find requirements for incineration, requirements for landfills, etc. Chapter 11 (Hazardous Waste) defines frames for when waste become hazardous waste and deals with storage, transport, and treatment of such waste. Chapter 14 regulates the procedures of the collection and destruction of PCB-containing insulating glass windows (Avfallsforskriften, 2016). This chapter says nothing about prohibition of reuse of such windows, but this is regulated in "Product Regulation" chapter 2-1, where it states that "It is forbidden to trade, use and reuse finished products with PCBs" (Produktforskriften, 2019a).

3.9.3 Pollution regulations (Forurensningsforskriften)

Regulations on pollution control (Pollution Regulations) are largely dealing with pollution of soil, water (watercourses) and air. The application area of this regulation has little relevance for reuse of construction materials. This regulation is administrated by the country governor (Fylkesmannen) and the purpose is to avoid pollution (Forurensningsforskriften, 2016a).

The main appeal of the Pollution Control Act is that it is prohibited for everyone to do or implement anything that may cause the risk of pollution without being legal (Forurensningsloven, 2019, §7, first paragraph). Further, according to §32 of the Pollution Control Act, industrial waste in principle should be brought to a legal waste facility. “Waste can be also recovered, so that it either ceases to be waste or otherwise benefits by replacing materials which otherwise have been used” (Forurensningsloven, 2019). If someone wants to recover waste, he must anyway ensure that the use of recovered waste does not violate the pollution ban (Forurensningsloven, 2019, §7).

3.9.4 Control of health and environmentally hazardous substances in construction products

3.9.4.1 Product Control Act (Produktkontrolloven)

Purpose:

a) “prevent products and consumer services from causing health damage, including ensuring that consumer products and services are safe;
b) prevent products from causing environmental disruption, including disruption of ecosystems, pollution, waste, noise and the like;
c) prevent environmental disruption by promoting efficient use of energy in products” (Produktkontrolloven, 2019).

Relevance to reuse of construction materials and products:

In principle, reuse of construction materials and products will help to prevent environmental disruption from waste and by this meets part of purposes of the law. To prevent health damage there is an important requirement: products and materials should not contain any health/environment hazardous substances. Thus, used construction materials and products, which have been checked and possibly sanitized for contamination, meet the requirements of the Product Control Act (Asplan Viak, 2018).

3.9.4.2 Product regulations (Productfofskriften)/ Chemical regulations REACH (REACH-forskriften)

Purpose:

The regulations related to restrictions on the manufacture, import, export, sale and use of chemicals and other products hazardous to environment and health (Productfofskriften) is intended “to prevent some hazardous substances or mixtures of such substances causing health or environmental damage" (Produktforskriften, 2019a). The Product regulations regulate a number of substances and mixtures of substances that can be found in reused products and materials, thus making reuse of them illegal. Relevant substances are: asbestos, PCB (polychlorinated biphenyls), mercury, short-chain chlorinated paraffins (SCCPs), Deca- BDE (decabromodiphenyl), chrome wood, EEE- products (electrical and electronic products) that do not meet RoHS requirements, and buildings with CFCs (chlorofluorocarbons). Substances with very undesirable properties (Substances of Very High Concern) are listed in the candidate list under REACH, Annex XVII (REACH-forskriften, 2020). If substance is included in candidate list, businesses have obligation to provide information to customers, consumers, and the authority.

Relevance to reuse of construction materials and products:

Similar as to 2.4.1. Product Control Act: used construction materials and products, which have been checked and possibly sanitized for contamination and are not affected by the prohibitions in Annex XVII or Product Regulations, meet the requirements of the Product Regulations/ Chemical regulations. Annex XVII regulates a variety of substances and mixtures of substances that can be found in reused products and materials, thus making reuse of them illegal. Typical substances are: PCTs (Polychlorinated terphenyls), asbestos, PBBs (Polybromobiphenyls, Polybrominatedbiphenyls), mercury, arsenic, organic tin compounds, pentachlorophenol, cadmium, creosote, short-chain chlorinated paraffins (SCCPs), penta-BDE (pentabromo diphenyl ether), octa-BDE (octabromodiphenyl ether), chromium and Deca- BDE (decabromodiphenyl). It is not necessary that all these provisions will be applied to reused products and materials, it requires separate investigation for each product (Asplan Viak, 2018). For surface treatment of structures of steel, different types of contaminates in paint create obstacles for reuse, but not all of them. There are no special requirements in the chemical legislation for painted components of steel which contain zinc, PAH (polycyclic-aromatic hydrocarbons) or bisphenol A. Nevertheless, it is not allowed to reuse products and materials containing short-chain chlorinated paraffins according to § 4-1 of the Product Regulations. Chlorinate rubber paint may contain PCBs and because of this is prohibited according to § 2-2 of the Product Regulations (Produktforskriften, 2019a).

When it comes to reuse of concrete waste with light pollution, there is a separate guide for reuse options. Concrete and brick waste can be contaminated by hazardous substances and toxins such as PCBs, PAHs and heavy metals. Norwegian Environment Agency believes that the biggest part of heavy construction masses (concrete and bricks) are clean enough to be used for useful purposes. However, in many cases, some substances like PCBs or hexavalent chromium prevent the recovery of such masses (Miljødirektoratet, 2020).

3.9.5 Other requirements for products in construction

3.9.5.1 Construction Products Regulation (Byggevareforordningen)/Requirements for CE marking

Purpose:

Regulation on documentation of construction products (DOK9) contain rules for documentation and turnover of construction products. The Regulation targeting manufacturer or the trade department. Chapter II of the Regulation implements the Construction Products Regulation (Regulation (EU)No 305/2011) in Norwegian law. The Construction Products Regulation contains requirements and rules for CE marking of construction products. The CE marking applies to the construction products and materials where there is a harmonized standard and where the manufacturer has chosen to perform a European technical assessment of the construction product or materials. If there is a harmonized products standard, it means that construction products and materials should be CE marked and have performance declaration (documentation). Chapter III, § 9-13 of the Construction Products Regulation contains requirements for non-CE marked construction products. These are applied in cases where there is no harmonized standard, or the manufacturer has not chosen to perform a European technical assessment (Byggevareforordningen, 2020). There is a new requirement, attached to the Construction Products Regulation, which is related to sustainability of natural resources use and it says: "Buildings should be constructed, operated and demolished in such a way that ensure sustainable and safe use of natural resources:

a) a construction, parts of construction and materials can be reused or recycled after demolition
b) construction's resilience
c) use of environmentally friendly raw materials and secondary materials in buildings" (Byggevareforordningen, 2020).

In other words, to support reuse is a basic requirement of the Construction Products Regulation. However, in practice, there is little evidence that this requirement is being followed up.

Relevance to reuse of construction materials and products:

When reuse of materials happens on-site rehabilitation construction project, used materials will be not affected by the Regulation, since these components and materials never reach the market, and are reused by the same owner (Sørnes et al., 2014). However, when selling of used construction products and materials take place, documentation requirements in accordance with DOK will apply. This means that if the seller does not have required documentation, the sale of used products and materials will be illegal. This means that documentation requirements for reused construction products and materials are the same as for new materials. The consequences of following this regulation, are that reused products and materials become very expensive and that "reuse projects" become very complex. In practice, however, these requirements for documentation are rarely followed up. If used materials came with the same type of documentation as new ones, it would make the process of comparison of used materials and different types of new materials easier. As an example, Danish company "Gamle Mursten" through a project supported by the Ministry of the Environment, established its own procedure for CE marking of old brick in accordance with EU regulations (Gamle Mursten, 2020). In principle, there is nothing preventing introduction of the similar procedure for all categories of used materials. If there is a documentation for products and materials in a demolition project, and the products have not changed their properties after use (including disassembly and storage), products' documentation can be used for sale of materials. In a future perspective, with full digitalization of building information (BIM), information on construction products' documentation will be easily accessible and this accessibility will promote reuse of materials (Asplan Viak, 2018).

3.9.5.2 Technical Approval (Teknisk Godkjenning TG)

The technical approval (TG) includes documentation of relevant characteristics of a product. The scheme is optional, but despite this, technical approval is often perceived as necessary to get access to the Norwegian market. Technical approval can also be performed for used products, but in practice it involves in the most cases small quantities of used construction products and because of this will make them more costly (Asplan Viak, 2018).

3.9.6 General requirements for buildings

3.9.6.1 Fulfillment of Technical Regulations (TEK)

Technical Regulations (TEK) have a number of requirements and regulations related to environmental performance in buildings. Chapter 9, External environment specifies provisions of importance for resource use and waste management.

§ 9-1 General requirements relating to the external environment: “Structures shall be designed, constructed, operated and demolished, and waste managed, in a manner that results in the least possible impact on natural resources and the external environment” (TEK17, 2017). The construction waste should be treated accordingly.

§ 9-2 Substances posing a health or environmental risk: “Construction products shall be chosen that have no or a low content of substances posing a health or environmental risk” (TEK17, 2017).

§ 9-5 Construction waste:

1) “Structures shall be ensured a justifiable and intentional lifetime such that quantities of waste over a structure's lifetime are kept to a minimum.

2) Construction products suitable for reuse and material recovery shall be chosen” (TEK17, 2017).

§ 9-7 Mapping of hazardous waste and environmental restoration plans:

1) “When implementing measures in existing buildings, mapping of building parts, and installations, which can constitute hazardous waste, must be carried out” (TEK17, 2017).

Environmental restoration plans should contain, among other things, information about occurrence and amount of hazardous waste, and how the hazardous waste is planned to be removed. Based on product documentation, it must be always considered, whether a construction product will contribute to fulfillment of Technical Regulations (TEK) in the building where it is intended to be used. The responsibility for this consideration typically lies on the design architect/ consultant or entrepreneur (Sørnes et al., 2014).

References to standards

According to Technical Regulations for Planning and Building Act (Plan- og bygningsloven), provisions and requirements in the Technical Regulations can be considered fulfilled if used methods and execution correspond to the Norwegian Standards. The challenge for used products is that standards are generally based on use of new products with relevant documentation.

According to (Widenoja, Myhre, & Kilvær, 2018), the reuse of steel can be met by writing in the standard that it is possible to use other and older types of steel if it can be documented that the steel material has the same or better properties than the steel types identified in the standard. In the same way, all standards related to construction materials can be rewritten to also describe requirements for used materials (Asplan Viak, 2018).

Construction Client Regulations (Byggherreforskriften)

“The purpose of the Regulations is to protect employees from risks, by taking into consideration safety, health and working environment on construction sites in connection with planning, design and execution of building or construction works” (Byggherreforskriften, 2016). For demolition work, where materials are planned to be reused and manual disassembly is prioritized over mechanical demolition, the Construction Client Regulations are likely to have increased significance (Asplan Viak, 2018).

The theoretical part of this paper gave us overview of circular economy implementation in construction sector by explaining link between C&DW and circular economy and explained how circular economy can be implemented in construction sector, how construction sector can be transformed in future, what is current situation in construction sector in Norway and other EEA countries and why materials reuse is an important tool in circular economy transition process, challenges for materials reuse in the EU countries. Legal framework for materials reuse in Norway helps us to understand why legal barriers for materials reuse emerge.

In the next part of this paper, we will study barriers for construction materials reuse as they perceived by the local actors operating in construction sector by collecting and analyzing empirical data in Trondheim region.

4 Empirical data

In this part of the paper, empirical data on construction materials reuse in Trondheim, in form of SWOT-analysis results, will be presented. Analysis section will be focused on challenges/barriers for construction materials reuse scaling up in Trondheim region and possible solutions for overcoming those barriers will be suggested in recommendations section.

4.1 Collected data – SWOT-analysis

In this chapter, I will present results from my research that was focused on assessment of current phase of construction materials reuse phenomenon in construction sector in Norway, Trondheim region. At first, I am going to present results from SWOT-analysis of each participant separately, where I will present company/organization participant, results from the SWOT-analysis and relevant data from discussion meeting. I will shortly analyze all four sections of the SWOT-analysis for each participant. The aim is to identify some points each participant is focused on. By this identification, we will see if there are some specific points in each participants vision of materials reuse phenomenon scaling up. Further, I will make analysis of the SWOT-analysis forms focused on challenges/barriers for materials reuse scaling up in Trondheim. Then, I will summarize and identify main challenges, which will be considered in more details in the latter chapters. I will propose solutions for those challenges/barriers and compare them with ones from different reports mentioned earlier in this paper.

4.1.1 Trondheim municipality, Real estate department (Trondheim eiendom)

Trondheim municipality plays an important role in the construction sector of Trondheim, that is why I chose real estate department to participate in my research.

The real estate department has overall responsibility for the buildings owned by the Trondheim municipality. Trondheim municipality owns an area of over 1,200,000 m^2. Its building stock consists of schools, kindergartens, health homes, cultural and sports buildings, administration buildings, as well as 4000 municipal rental housing. The real estate department has an operating budget of NOK 1 billion a year. When the Trondheim municipality is to rebuild, rehabilitate buildings or start new construction projects, it is the real estate department who is responsible for the development and planning of the work (Trondheim Kommune, 2020).

Table 6.: SWOT-analysis matrix for "construction materials reuse" phenomenon filled by Real estate department of Trondheim Municipality, 2020.

	Helpful	Harmful
Internal	**Strengths**	**Weaknesses**
	- Can contribute to reducing the climate footprint of the building, depending on the component or material. - Can contribute to reducing the demand for virgin material. - Can lower the costs linked to waste handling in the building projects.	- Can contribute to increasing the carbon footprint of the building, depending on the component or material (e.g. because of additional transport need or need for redesign/remanufacture). - Can increase the costs linked to demolition. - Can increase the time spent on demolition. - Need for organizing the building projects in a different way
External	**Opportunities**	**Threats**
	- Emergence of new markets and business opportunities for companies specializing in testing, re-certification, or "gentle" demolishing. - Can contribute to closing "the loop", meaning contributing to circular buildings, and through this support the movement towards a circular economy. - Can lead to new ways of thinking and new ways of conducting a building project. - Can lead to interesting new designs and expressions through less traditional solutions and material choices. - Can lead to development of new technologies for testing used materials and contribute to making these more available.	- Might lead to "green washing" since it's not given that the introduction of reused materials will contribute to reducing the carbon footprint of the building. - Need for testing and re-certification of "high risk" materials such as concrete slabs and steel beams, which might also be the components contributing to the highest carbon reduction when reused. - Lack of the infrastructure needed to successfully implement used materials (e.g. physical storage, logistics), and the link between the phases in a building project (e.g. what materials are available at start of a new project, when will materials be available in the demolition projects). - Lack of competence and experience in construction firms, among architects and others. - If introduced on a large scale: Can affect already established industries and markets (e.g. suppliers of products based on virgin materials). - Today's standards and regulations: They are not necessarily suited for used materials.

Source: (Trondheim Municipality, 2020)

From the SWOT-analysis form, one can see that Trondheim Municipality sees environmental, economic, social, and systemic opportunities related to scaling up of construction materials reuse. Through a personal short online interview and SWOT-analysis I made a conclusion that lack of technologies and tools for testing and re-certification of used materials and products and also underdeveloped market (with lack of physical storage, logistics, and information on supply and demand) are two main barriers for materials reuse scaling up from the Trondheim Municipality perspective, since they were mentioned as threat and as an opportunity for improvement in SWOT-analysis and also in the interview:

Me: "Do you think regulation is the point where construction sector has to start its transformation to improve materials reuse?"

Trondheim Municipality: "I'm not really sure where it should start, but that's very important point as well. But I don't know what comes first, the egg or the chicken. If we have a storage space, but we don't have certification on the materials, that we want to use, then there is no point. So, I guess we also have to have these regulations and also maybe test methods so than I *can say OK this is actually good enough, you can use it. Especially, if you want to use more high-risk materials. We also need to think a bit new, because we can't just think: OK we want to reuse this window as the window, maybe we can reuse the window as something else… we'll have to start doing this that's like easy first step: Reuse things maybe like something else try to design stuff like making wall out of windows"* (Trondheim Municipality, 2020,a).

There were also other barriers mentioned in the SWOT-analysis form, related to the environment, economy, and market development. All of them will be analyzed in analysis section.

4.1.2 Trøndelag County Council, Department of Planning, Industry and Cultural Heritage

Trøndelag County Council is responsible for developing the region in several ways. It provides upper secondary education, dental health services and public transportation. Trøndelag County Council is also in charge of most of the public roads, a variety of cultural activities, environmental issues and contribute to the economic growth and development of the region. Trøndelag County Council owns buildings with a total area of approx. 500,000 square meters, mainly secondary schools, transport buildings and some of our dental clinics. The Property section manages the buildings.

Table 5.: SWOT-analysis matrix for "construction materials reuse" phenomenon filled by Trøndelag County Council, 2020

	Helpful	Harmful
	Strengths	**Weaknesses**
Internal	• Reduce resource consumption • Reduce waste • Reduce climate footprint • Create new jobs in preparing for reuse • Help towards a more sustainable construction industry • Reuse is in fact an overall requirement- there is not sufficient materials for all new buildings to be based on virgin materials	• Lack of documentation may cause difficulties and prevent reuse • Some materials may have lost their performance capacity • Some materials may contain harmful components • Reuse of materials require more planning and preparation before demolition • Demolition for reuse is more time consuming • Reuse will require a new approach for architects and enginers when planning and preparing for usage in new constructions
	Opportunities	**Threats**
External	• Reuse may create new exiting design possibilities • Reuse will create new jobs • Reuse will create new social structures and open for new and sustainable ways of living • Possibilities for a transition towards a sustainable way of living • Possibilities to use digital technologies (3D printing…) for repair and maintenance	• Regulations and requirements for documentation and general approval may prevent reuse • Reuse will be opposed by the existing manufacturers of virgin building materials • Lack of documentation may prevent reuse • Lack of manufacturers of the original materials may cause challenges in availability of spare parts and repair possibilities

Source: (Trøndelag County Council, 2020)

Based on the SWOT-analysis form results, one can say that Trøndelag County Council sees many environmental, social and economic benefits related to materials reuse scaling up in construction sector in Trondheim: reduced resource consumption, reduced waste, reduced climate footprint, sustainable ways of living, new jobs and new social structures creation. At the same time, they see many challenges/barriers related to quality of used materials (harmful components, which lost their performance capacity), technological challenges (lack of manufacturers of the original materials, more planning and preparation before demolition, demolition for reuse is more time consuming), traceability (lack of documentation), and legal issues (regulations and requirements for documentation). Based on this SWOT-analysis form and several conversations with Trøndelag County Council staff, I concluded that their vision of materials reuse barriers is focused on quality of used materials, technological challenges for reuse, traceability, and legal issues. Those barriers will be analyzed in next section.

4.1.3 GreenStock

GreenStock is a start-up company, established in 2018 by architects from NTNU in close dialogue with property owners and the construction industry. The main goal of this company is to reduce global material waste. This company developed digital purchasing platform, where customers can get an overview over available construction materials on the market, share information with partners and get help related to logistics, technical or legal issues, as well as view detailed reports on potential savings - economy, construction waste and CO2 (GreenStock, 2020). This company makes a lot to make materials reuse easier.

Table 6.: SWOT-analysis matrix for “construction materials reuse” phenomenon filled by GreenStock, 2020

	Helpful	Harmful
	Strengths	**Weaknesses**
Internal	• Environmentally right, saving natural resources; • decrease landfill; • decrease CO^2; • redefine construction industry by putting reuse at the center; • influence product industries; transition to reuse friendly products;	• lack of expertise on reuse; • lack of concrete examples; • financial cost of reuse is too high with currency process; • lack of reuse friendly processes in the industry; • difficult to define the quality of the materials; • lack of documentation on used materials; • legal responsibility issues; • “not new” look is different; • procurement procedures are unfamiliar with reused materials; • unclear regulations regarding reused materials; • it takes too long to form new EU regulations;
	Opportunities	**Threats**
External	• creating new business opportunities: dismantling, testing, transporting, storage, redesign etc.; • technology for collecting data on the materials; • educating building owners and industry on circular process and opportunities there; • data on circularity of buildings; • exchange of reused materials between different organizations leads to efficiency and additional revenue from reused materials; • new ways to manage building portfolios;	• too strict regulations; • unwilling customers; • unwilling industry players, especially producers of materials; • authorities` low will to act; • high cost of testing, storing and transporting of materials; • desire of new and nice things; • technological barriers in creating reuse platform.

Source: (GreenStock, 2020)

From the SWOT-analysis form, one can see that GreenStock sees in materials reuse scaling up potential for improvement of construction sector’s environmental impact through: saving of natural resources, decreased landfill, and decreased CO2. They also highlight that with materials reuse improvement, construction sector can be redefined by putting reuse at the center, where production of construction products will be based on principles of design for reuse. GreenStock also sees the following possibilities: creation of new business possibilities (dismantling, testing, transporting, storage, redesign); development of technologies for collecting data on the reusable materials, and data on circularity of buildings; development of industrial symbiosis; new approaches to manage building portfolios; and emergence of educational programs for building owners and other industry actors on circular processes and opportunities there. Challenges/barriers that GreenStock highlight in the SWOT-analysis form are related to underdeveloped infrastructure and market for construction materials reuse performance (lack of expertise, lack of concrete examples, lack of reuse friendly processes,), legal issues (unclear regulations, too strict regulations, long time to form new EU regulations, unfamiliar with reused materials procurement procedures), quality of used materials (difficult to define the quality), traceability (lack of documentation), responsibility (legal responsibility issues), technological barriers (technological barriers in creating reuse platform), economics (too high financial cost of reuse, high cost of testing, storing and transporting) and linear thinking issues (unwilling customers, unwilling producers of materials, authorities` low will to act, customers desire of new and nice things). One can see that challenges related to underdeveloped infrastructure and market for construction materials reuse performance, legal barriers and linear thinking issues are the most relevant for scaling up of materials reuse from GreenStock perspective.

In this section, all results from SWOT-analysis research were presented and some specific points in each participant's perspective of materials reuse scaling up were identified. Thus, we can see that lack of technologies and tools for testing and re-certification of used materials and products, quality of used materials, traceability, challenges related to underdeveloped infrastructure and market for construction materials reuse performance and legal barriers are main barriers for scaling up materials reuse in Trondheim region. In the next section, we will analyze those main barriers in more details and compare them with the ones listed in Asplan Viak (2018) report.

4.2 Main barriers

In this section, the main challenges/barriers that were identified during data collection and barriers described in the Asplan Viak (2018) report on barriers and opportunities for reuse of building materials and technical installations in buildings in Norway as a whole will be considered.

4.2.1 An underdeveloped market

To make the picture clear, one can say that the demand for reused materials in the professional part of the construction sector is close to zero. In exceptional cases, museums and other projects operating with antiquarian rehabilitation are looking for materials for restoration and repair purposes, or when some specific pilot projects with high environmental focus take in reused materials and products to reduce greenhouse gas (GHG) emissions. There is some activity in the private market, which is represented by finn.no website. Single initiatives, like Resirqel in

Oslo and GreenStock in Trondheim work targets to scale up reuse on professional construction market (Asplan Viak, 2018). There are many reasons for underdevelopment of reuse market:

- Information on used materials is hardly available.
- The sale of used materials challenges suppliers of new ("linear") materials.
- Reuse complicates construction projects because it is hard to control deliveries of materials in a habitual for architects, consultants, and project managers way. In some cases, buildings must be designed based on access to material and the result can be different from ideal one.
- Knowledge of what is legally allowed to reuse can represent an obstacle. For instance, PCB-containing windows are forbidden to reuse, while windows containing chlorinated paraffin are allowed to reuse.
- Challenges with certification and product guarantees of used materials create insecurity (Asplan Viak, 2018).
- The typical process of construction demolition involves destruction of materials. Reuse, in most cases, requires disassembly of materials and building components, and gentle transportation for further transport or intermediate storage. As long as demolition contractors do not see an adequately paying market for reusable materials and products, they will choose mechanical demolition and removal using containers. Thus, avoiding waste treatment costs could be a powerful driver for finding alternative solutions.
- As it was said above, reuse requires disassembly instead of demolition, but disassembling takes more time and costs more than demolition.
- Many construction components and materials, especially those used in buildings in period after 1940/50s, are not suitable for reuse because they are not demountable or contain toxins or are of poor quality.
- The existing buildings consist of big number of different components and materials, which makes it challenging getting large enough amount of the same reused units for use in new builds.
- Logistics. Usually reused materials must be moved to intermediate storage, often in several stages (Asplan Viak, 2018).
- Access to the construction site. Because of "Heals Environment and Safety" (HMS) regulation and general requirements to safety on a construction site, it is challenging for external actors to get access to the construction site for disassemble construction materials and components. This means that in practice private actors have no possibility

to extract reused materials. One good example of this is when construction components from Ruseløkka school were posted on finn.no, but with the requirement that interested parts must have the responsibility right to enter and perform disassembly in the building. Thus, one can see that the market for reused materials is not developed because of insufficiency of economic and other driving forces. The interest to the circular economy, reduced GHG emissions and better resources' utilization can change this picture, but the market of reused materials still needs growth impulses to become something big and serious. A major challenge is related to access to information on available used construction materials and components. There are no established platforms or market channels that gather and carry such information and that can help sellers and buyers to find each other for cooperation. This means that even if a developer wants to start using reused materials in his projects, it is hard to find secure sources (sellers) of such materials, which at the same time will provide information on properties and conditions. Building owners and demolition constructors, who own and manage reused materials, do not see current buyers with enough willingness to pay. As a result, buildings and constructions are demolished and used materials are transformed into construction waste (Asplan Viak, 2018).

4.2.2 Technological challenges

The introduction of the circular economy into the construction industry requires the establishment of new approaches to structuring of construction cases. Both construction and demolition processes in circular economy can be more time-consuming and lead to additional costs. In addition, these new approaches require establishment of new types of expertise both in design and operation. The design must be based on available materials and components, not the other way around, one should be more active to find suitable materials and components on the reused market. Regarding demolition, construction materials must be disassembled in higher extend and be carefully treated instead of mechanical tearing them down. Further, the materials must be transported and stored in intermediary stocks without reduction of their quality and properties. In practice, this means extended time spent on the process of demolition and increased related costs. Timing in the procurement and delivering of materials becomes significant. It is a great advantage to have a storage available to store appeared relevant reused materials until the beginning of construction process. But intermediary transportation and storage will increase costs and reduce quality. “Just in time” delivery is possible if system and market are developed to that extent when it is possible to buy used materials and components directly from buildings that have not yet been demolished (Asplan Viak, 2018).

4.2.3 Quality control challenges

One challenge for used construction materials and components is that they in most cases lack documentation and guarantees in the same form as new construction products have. For designers and engineers, who want to use used materials in their projects, lack of information and documentation leads to additional efforts to meet quality requirements in new buildings. There is a big number of properties and characteristics related to construction materials and products, such as: fire properties, thermal resistance, mechanical strength, airtightness, soundproofing ability, rainproof, vapor density and content of hazardous to health and the environment substances. The different characteristics can be of varying importance to different use purposes of the same product. Usually, used materials and products are used in secondary functions with lower quality requirements. For instance, used windows can be repurposed from use on exterior wall to use on interior wall with reduced U-feature requirement. Therefore, it is important to consider what are the real requirements to used materials in a new building. In relations to the constructive properties, it is not unusual for used items to be divided into smaller units and incorporated into new constructive frames. The most efficient resource use can be reached by performing good technical control procedures. This will increase possibility to lift a used product from secondary functions to the same function as it was designed to. It will also increase market value of the product. A form of performance declaration, which describes the material properties, can be useful as a basis in design of a new building and is required for revenues/sales (Asplan Viak, 2018).

4.2.4 Legal/formal barriers

Laws, regulations, and standards related to construction materials and products were recently developed to ensure the appropriate waste treatment on the one hand, and to safeguard the quality of products and materials for use in buildings on the other hand. To move a product or material from a building A, which going to be demolished, to a new building B, different considerations should be taken at different stages. Today, the potential of circular value chain is not fully reflected in the legal texts, and because of this it is not clear to which extent the regulations prevent the legal reuse of construction materials and products.

In this section, the challenges associated with three actors, which together form the basis for the construction materials reuse, will be presented. These actors are demolition constructors, sellers of reused products, and new buildings constructors.

Which challenges legal barriers can create for reuse at demolition/waste management?

The regulations on waste are linked to the risk of contamination and requirement for proper treatment of hazardous for health and environment substances. Materials containing hazardous, for health and environment, substances must undergo environmental sanitation before demolition, or they must be delivered to an appropriate reception center. Slightly contaminated materials can be used for some specific purposes following application to the Country Governor. The final report should document how the waste was delivered/used. The main rule is that products and materials, with exceeding content of hazardous substances, must be out of the cycle and not reused. However, not all types of hazardous for health and environment substances cannot be reused. Annex XVII regulates substances and mixtures of substances which can be found in reused products and materials, but a separate study is required to define which of these provisions will apply to reused products (REACH-forskriften, 2020).

The ownership of demolition materials should be clarified in a contract between the building owner and the demolition contractor. If the building owner wants to keep the materials for his own use or sell them at his own expense, this should be described in the tender (Asplan Viak, 2018).

Which challenges legal barriers can create for reuse at third party trade?

An actor, who sells used construction materials and products takes ownership of the materials for a period of time. As mentioned above, used products and materials, with exceeding content of hazardous substances, should not be reused and therefore cannot be traded. The Construction Products Regulation applies to both new and used construction materials and products if they are traded. If used construction products have their original documentation and they maintained the original properties, this documentation can be used for sale of these products. These regulations are also applicable for sale to private actors. If used construction products are sold on finn.no or reuse shops, the documentation on them should correspond to DOC (Byggevareforordningen, 2020). If a seller does not have appropriate documentation, the goods are illegal to sell. If these regulations are to be followed, the consequence is that reused products and materials can become very expensive and that “reuse projects” will become very complex. In practice, however, these requirements are rarely followed up (Asplan Viak, 2018).

Which challenges legal barriers can create for reuse in new buildings?

Based on product documentation, it must be always considered, whether a construction product will contribute to fulfillment of Technical Regulations (TEK) in the building where it is intended to be used. This applies to both new and used materials. The responsibility for this consideration typically lies on the design architect/consultant or entrepreneur (Sørnes et al., 2014). As described in section above, materials with exceeding content of hazardous substances, cannot be reused. Properties of materials are related to different topics such as fire properties, mechanical strength, thermal resistance, soundproofing capability, airtightness, rain density, and vapor density. The challenge with construction materials reuse is that documentation is rarely follows, and it can be complicated and time-consuming to test the required properties before using materials in new buildings. Today's regulations for trade and documentation of construction materials do not distinguish between new and used materials. As it is often challenging to obtain documentation for used materials, the regulations therefore contribute to inhibiting rather than promoting of reuse. This contradicts the authorities' desire to promote a circular economy and effective use of resources. (Trafik- Bygge- og Boligstyrelsen, 2016).

Thus, one can see that, the most important market, organizational and technical barriers in Norwegian construction sector are interconnected and are linked to:

- An underdeveloped market for professional players, because of insufficiency of economic and other driving forces. Construction process with reused materials becomes time-consuming and expensive due to additional time for disassembly and engineering and uncertainties related to used products' documentation.
- Lack of information on available used materials and products, especially with time perspective which can give them possibility to be included in design process of new building.
- A regulation that is not designed to handle the reuse and sale of used construction materials and products (Asplan Viak, 2018).

In the next section all challenges/barriers from SWOT-analysis will be gathered, categorized, analyzed.

5 Analysis

In this chapter, I am going to use table "Challenges in implementation of circular principles in the management of construction and demolition waste" from (Wahlström et al., 2020, p. 35) report which is called "Construction and Demolition Waste: challenges and opportunities in a circular economy" and was presented in section 3.6 above. This table will serve me as a basis for analysis of collected in SWOT-analysis challenges/barriers for scaling up construction materials reuse in Trondheim region. In my modified table, I collected all Weaknesses and Threats from all research participants, from now they are called challenges/barriers. I classified and divided all the challenges/barriers on several categories in accordance with the original "Wahlström table" and added several new categories. The "Wahlström table" contains the following categories of challenges/barriers: quality of used materials (originally it was "quality of waste"), technological challenges, economics, traceability, responsibilities, technical requirements, legal issues, environmental aspects. I added two new categories: reused materials market underdevelopment and linear thinking. Thus, all Weaknesses and Threats (challenges/barriers) from my SWOT-analysis are classified according to those categories. For each challenge/barrier category, there are cells with: Specification (short description of categories' challenges), Trondheim challenges/barriers from SWOT-analysis (results from SWOT-analysis), Comments/analysis (some comments related to challenges/barriers from SWOT-analysis), and Potential solutions for removing of challenges/barriers (some actions/recommendations as potential solutions are provided based on data from reports collected in this paper).

Table 7: Challenges/barriers on the way to materials reuse scaling up and possible solutions. Trondheim region.

Challenge/barriers	**Specification**	Trondheim challenges/barriers for **construction materials reuse** from SWOT-analysis	**Comments/analysis**	**Actions/recommendations as potential solutions for removing of challenges/barriers**
Quality of used materials	- Heterogeneity (use of complex materials or multi-materials components); - Too high content of impurities; - contain hazardous substances; - Lack of traceability (lack of documentation and guarantees); - material degradation during use.	- Difficult to define the quality of the materials; - Lack of documentation on used materials; - Materials may contain harmful components; - Materials may have lost their performance capacity.	- In the most cases, used construction materials and components lack documentation and guarantees in the same form as new construction products have. For designers and engineers, who want to use used materials in their projects, lack of information and documentation leads to additional efforts to meet quality requirements in new buildings. - Without access to documentation on used materials it is hard to assess their performance capacity. - Use of multi-material components can cause challenges for reuse and recycling of construction materials and products. - Hazardous substances also cause challenges for materials reuse.	- Use of less complex construction materials and products. - Performance of pre-demolition audits with follow-up checks on the removal of contaminants prior to demolition and identification of reusable products and materials (Wahlström et al., 2020). - Performance of selective demolition. - Improvement of link between pre-demolition audit and re-certification (European Commission, 2017). - Introduction of sensors in products for securing traceability. - Development of tools for detecting product degradation/ageing. - Development and standardization of methodology for testing and re-certification of used materials to define quality of materials (Wahlström et al., 2020). - Consideration of the real requirements to used materials in new application can simplify product's properties assessment. - Performance of good technical control procedures for materials and products, during use phase, can increase value of used product. - Performance of environmental sanitation for materials containing hazardous substances before demolition or delivering them to appropriate reception centers. - Slightly contaminated materials can be used for some specific purposes following application to the Country Governor. - The final demolition report should document how the waste was delivered/used. (Asplan Viak, 2018). - Creation of a material passport during construction. - Update building information models and its material passport during use; - Monitoring demolition and renovation work to assure (trust in) material quality for recycling and reuse. - Increase traceability, quality assessment and certification of C&DW streams. - EU Construction and Demolition Waste Management Protocol: aims to ensure recovery of valuable resources and adequate waste management in the construction and demolition sector (European Commission, 2016a).

Challenge/barriers	Specification	Trondheim challenges/barriers for **construction materials reuse** from SWOT-analysis	**Comments/analysis**	**Actions/recommendations as potential solutions for removing of challenges/barriers**
Technological challenges	- Demolition for materials reuse becomes time-consuming and expensive. - Complex products may require multiple processing steps before reuse or recycling, increasing total cost and time. - Demolition for reuse can increase health and safety risks. - Processing needs for new rejects.	- Reuse of materials require more planning and preparation before demolition. - Demolition for reuse is more time consuming - Reuse will require a new approach for architects and engineers with planning and preparing for usage in new constructions - Lack of manufacturers of the original materials may cause challenges in availability of spare parts and repair possibilities - Technological barriers in creating reuse platform - Need for organizing the building projects in a different way	- Requirement of longer time for deconstruction and demolition can be unappealing in cases where extra costs are incurred through having a building (such as local property taxes) or through loss of revenue on a replacement building related to extended scheduling of works. Time can be also limited because of planning permission expiration (Hobbs & Adams, 2017).	- Development of new technologies and business models focused on demolition for reuse (such as REBRICK, mechanical brick cleaning system in Denmark). - Implementation of “design for disassembly” concept. - Development of projects’ planning that includes procurement practices that promote use of reclaimed products and materials. - Motivation of greater collaboration between asset owners and technology companies, operators, platform developers and other industry actors can stimulate emergence of technical innovations, cut costs, increase trust amongst partners, and resource use reduction. - Support of innovations and start-ups that will facilitate development of technologies for materials reuse improvement. - Performance of good technical control procedures for materials and products, during use phase, can increase value of used product and eliminate needs for repair. - Improvement of sorting systems for materials that cannot be collected separately during demolition. - Adaptation of the recycling process needs to provide suitable feedstock for recycling and reuse, potentially adding new process steps for material separation.

Challenge/barriers	Specification	Trondheim challenges/barriers for **construction materials reuse** from SWOT-analysis	**Comments/analysis**	**Actions/recommendations as potential solutions for removing of challenges/barriers**
Economics	- Low price of virgin materials. - Demolition for reuse increases cost of used materials and products due to more work intensive, higher energy needs. - Testing, storage, and transportation of used materials lead to additional costs. - Lack of new business models for sharing of apparatus, facilities, etc.	- Reuse can increase the costs linked to demolition. - Financial cost of reuse is too high with current process - High cost of testing, storing, and transporting of materials.	- In comparison to virgin materials' prices (which often are low), demolition for reuse, disassembly of materials and building components and recovery of used materials can be more costly. - For cheap products and materials, the incentive to reuse, considering the cost of careful remove, can be low or negative. - Testing of product performance can be expensive and require annihilation of samples to mitigate risks of further use (additional costs to the purchasing price of the product and this may override savings for reuse) (Hobbs & Adams, 2017). - In addition, storage and transportation of used materials can be costly (Hobbs & Adams, 2017). - As long as demolition contractors do not see an adequately paying market for reusable materials and products, they will choose mechanical demolition and removal using containers (Asplan Viak, 2018). - *"The market acceptance of products produced using waste as an input material will only be assured when production costs are lower than for virgin materials"* (Wahlström et al., 2020).	- Governmental measures – landfill bans, taxes on virgin materials. - Promotion of green public procurement supporting reuse and recycling. - End-of-waste criteria. - Extended product responsibility implementation (Adams et al., 2017). - Sharing of process equipment. - Development of new technologies and business models that will be focused on demolition for reuse. - Development of projects' planning that includes procurement practices that promote use of reclaimed products and materials.

Challenge/barriers	Specification	Trondheim challenges/barriers for **construction materials reuse** from SWOT-analysis	Comments/analysis	Actions/recommendations as potential solutions for removing of challenges/barriers
Traceability	- Lack of standards and tools for used materials certification. - Lack of quality systems for complex materials. - Lack of information on available used construction materials and products.	- Need for testing and re-certification of "high risk" materials - Lack of documentation may prevent reuse	- Documentation is rarely follows used materials and products, and it can be complicated and time-consuming to test the required properties before using materials in new buildings. - Unwillingness to use materials and products without tested performance certification is one of the biggest barriers to reuse. - Restricted information on where the product has come from and how long it has been used.	- Standardization and commitments between stakeholders. - Introduction of requirements for obligatory information documentation and sharing. - Implementation of Building Information Modelling (BIM) - a tool for material inventories and traceability, it carries information about construction materials and products during their entire lifecycle up to the deconstruction phase. The use of traceability systems for reusable materials and products is a crucial tool for creating confidence among value-chain stakeholders. Traceability systems can be built on information collected during a pre-demolition audit, such as Tracimat. - Policy can promote traceability system, at least in government construction works contracted through, for instance, green public procurement. - Introduction of materials passports which contain details of the materials and components in construction products and allow maintenance, recovery, reuse, and recycling potential for construction materials and products at different stages and can be made available to all stakeholders at the right time. (Wahlström et al., 2020).

Challenge/barriers	Specification	Trondheim challenges/barriers for **construction materials reuse** from SWOT-analysis	**Comments/analysis**	**Actions/recommendations as potential solutions for removing of challenges/barriers**
Responsibilities	- Role of different actors is not clear. - Extended product responsibility not applicable for construction products with long lifespan.	- legal responsibility issues	- Lack of certification and product guarantees for used materials create insecurity (Asplan Viak, 2018). If there is no documentation, certification, and guarantee for used materials and products, correspondingly it is not clear who is responsible for quality of used materials and products. - Lack of link between the responsibility of a manufacturer and products that will only be demolished in several decades. - Lack of link between the ownership of construction material and responsibilities.	- Introduction of extended product responsibility for construction products (including construction products with long lifespan). - Clarification of the role of building owner (client or end user) in design and construction phase as they can influence the uptake of circular economy principles (choice of resources and materials).
Technical requirements	- Potential overspecification of virgin materials. - Standards and regulations not suitable for reuse.	- Today's standards and regulations are not necessarily suited for used materials.	- Standardization plays an important role in assessment of used materials (secondary materials). Standardization is often the basis for certificates that are used in trade and business. - Overspecification of virgin materials leads to overstated requirements to used materials during assessment of their performance capacity. As a result, materials that does not cover those requirements cannot be certified and sold to potential users. This leads to increased use of virgin materials (Wahlström et al., 2020).	- Development of new standards which will be focused on materials reuse. - Development of quality standards for secondary raw materials construction industries and improve rules on end-of-waste - The requirements to used materials that are related to different applications need to be checked, based on experience and tools availability. - Non-destructive testing methods for assessment of used products properties (including material degradation) should be preferred, considering safety targets of construction (Wahlström et al., 2020).

Challenge/barriers	Specification	Trondheim challenges/barriers for **construction materials reuse** from SWOT-analysis	**Comments/analysis**	**Actions/recommendations as potential solutions for removing of challenges/barriers**
Legal issues	- Regulation is not designed to handle the reuse and sale of used construction materials and products	- Unclear regulations regarding reused materials - Too strict regulations - It takes too long to form new EU regulations - Procurement procedures are unfamiliar with reused materials - Regulations and requirements for documentation and general approval may prevent reuse	- Regulations related to reused materials are not always clearly formulated. - Procurement procedures for reused materials are not clearly formulated it legal texts. - Today's regulations for trade and documentation of construction materials do not distinguish between new and used materials. As it is often challenging to obtain documentation for used materials, the regulations therefore contribute to inhibiting rather than promoting of reuse (Asplan Viak, 2018). - The procedure of formulation of new requirements and regulations regarding materials reuse in the EU and translation and incorporation of them into Norwegian law takes very long time.	- Development of regulations specified on materials reuse - Separation of regulations for trade and documentation of new and used materials - implementation of a dispensing scheme (Danish example), which allows municipal authorities to consider exemptions from documentation requirements, can be a first step on the way to increased reuse of construction materials (Trafik- Bygge- og Boligstyrelsen, 2016). - Improvement of mechanisms for quick reaction on changing construction materials market circumstances and adequate adjustment of regulations for materials reuse on the EU level.

Challenge/barriers	Specification	Trondheim challenges/barriers for **construction materials reuse** from SWOT-analysis	**Comments/analysis**	**Actions/recommendations as potential solutions for removing of challenges/barriers**
Environmental aspects	- Multiple processing steps before reuse of materials or products can increase level of emissions and environmental impact. - Lack of assessment tools for estimation of material or landfill savings during whole lifetime – focus mainly on greenhouse gas emissions. - Environmental impacts often case specific – local conditions, availability of alternative materials, transport. Risks for hazardous substances. - Lack of impact data that can promote reuse in preference to recycling.	- Reuse can contribute to increasing the carbon footprint of the building, depending on the component or material (e.g. because of additional transport need or need for redesign/remanufacture)- Reuse might lead to "green washing" since it's not given that the introduction of reused materials will contribute to reducing the carbon footprint of the building.	The environmental effect of materials reuse can be sometimes ambiguous. This happens because of lack of standardized procedures for treatment of used materials. This led to additional and in the most cases not efficient use of money and resources for instance for transportation or for redesign/remanufacturing of materials that lead to increased environmental footprint. Those action can be associated with "green washing" when more time, money and resources are spent on creation of environmentally friendly image, than on minimizing environmental impact.	- Standardization of procedure for treatment of used materials. - Develop further life cycle analysis indicators for the saving of natural resources – not only focus on greenhouse gases. - Promotion of local solutions where materials are not transported. - Promotion of the product lifetimes extension (Wahlström et al., 2020). - Spread of evidences of better environmental outcomes of reuse in comparison to recycling. - Support of implementation of calculation tool for environmental effect (LCA) of materials reuse. - R&D projects focused on existing buildings. - Optimization of demolition to promote reuse. - EU Level(s) – European reporting framework for sustainable buildings: aims to facilitate the assessment of the environmental performance of buildings (European Commission, 2019).

Challenge/barriers	Specification	Trondheim challenges/barriers for **construction materials reuse** from SWOT-analysis	**Comments/analysis**	**Actions/recommendations as potential solutions for removing of challenges/barriers**
Reused materials market underdevelopment. (Lack of facilities)	- Mismatch of supply and demand of reused materials in terms of quantity and quality. - Lack of facilities locally	- Lack of reuse friendly processes in the industry - Lack of the infrastructure needed to successfully implement used materials (e.g. physical storage, logistics), - Lack of the link between the phases in a building project (e.g. what materials are available at start of a new project, when will materials be available in the demolition projects).	- Materials reuse scaling up requires links between different phases of a project and between different projects (new building and demolition) with exchange of information on available materials and terms for when they will be available. -Space for storage of materials is expensive and limited in highly built up areas. This can cause a discrepancy between the location of the stocks of reclaimed for reuse items and the market where such items are demanded. Additional costs for storage will be added to price of items, this can reduce the attractiveness of reclaimed components and products compared to new. - In addition, reclaimed for reuse materials or constructions need to be transported over long distance to reach their markets, this can lead to significantly increased costs related to transportation and environmental impact.	- Development of mechanisms that match supply and demand linked to traceability mechanisms (stockholding facility, reclamation yards). - Development of material (waste) exchanges/reuse platforms, which directly connect those with surplus materials to those who need them. - Development of industrial symbiosis (European Commission, 2017). - Development of infrastructure for implementation of materials reuse with appropriate access to storage and logistics for reused materials. - Support of reclamation sector. For example, making public land available for reasonable costs can facilitate development of needed for reused materials facilities such as storage of materials. - Development of system and market to that extent when it is possible to buy used materials and components directly from buildings that have not yet been demolished ("Just in time" delivery) (Asplan Viak, 2018). - Implementation of new business models which will facilitate development of materials reuse.

Challenge/barriers	Specification	Trondheim challenges/barriers for **construction materials reuse** from SWOT-analysis	**Comments/analysis**	**Actions/recommendations as potential solutions for removing of challenges/barriers**
Lack of expertise, competence, and experience	- Lack of knowledge on technical requirements among demolition contractors. - Lack of knowledge on circular, reusable components and materials among architects.	Lack of competence and experience in construction firms, among architects and others.	Lack of knowledge on what is legally allowed to reuse can represent an obstacle.	- Familiarize stakeholders with the language of the circular economy and materials reuse. - Run staff training programs to raise awareness across all grades and disciplines in materials reuse field - Initiate targeted training sessions for leaders, project managers, and specific disciplines (Arup, 2016). - Increase awareness of architects about the demolition contractors work to make them able to choose suitable for deconstruction and demolition for reuse materials. - Increase awareness of demolition contractors and recyclers about the technical requirements of the recovered products or materials for reuse to make them able to provide materials that corresponds to quality requirement for new construction projects. - Spread information on best practices in materials reuse and implementation of circular economy practices (Wahlström et al., 2020). - Development and share of research that can challenge the industry to apply circular economy principles - Implementation of pilots to enhance knowledge and skills, build capacity and drive innovation in the construction environment (Arup, 2016).

Challenge/barriers	Specification	Trondheim challenges/barriers for **construction materials reuse** from SWOT-analysis	**Comments/analysis**	**Actions/recommendations as potential solutions for removing of challenges/barriers**
Linear thinking	- Consumer culture lays in the cents of linear economy's mechanisms of production and consumption - Slowly changing conservative (linear) thinking of construction sector's actors.	- "Not new" look is different - Unwilling customers - Unwilling industry players, especially producers of materials - desire of new and nice things - Reuse will be opposed by the existing manufacturers of virgin building materials	- Most of construction sector actors are not ready to accept principles of circular economy with materials reuse as a tool. Reasons for this unwillingness can vary and are in most of the cases related to those challenges and barriers listed in this table above.	- Spread of evidences of economic, environmental, and social benefits from materials reuse in comparison to virgin materials use. - Initiation of collaborative activities such as industry and client workshops to help identify joint challenges, exchange experience, expertise, and opportunities for strategic partnerships. - Initiation of conversations with clients to encourage them to consider adopting circular principles and materials reuse in their projects. - Governmental measures – landfill bans, taxes on virgin materials, green public procurement supporting reuse and recycling, end-of-waste criteria and extended product responsibility (EPR)(Adams et al., 2017). - Development of new technologies and business models that will be focused on circular economy principles and promotion of reuse. - Development of projects' planning that includes procurement practices that promote use of reclaimed products and materials. - Involvement and commitment of stakeholders throughout the value chain.

Source: (based on Wahlström et al., 2020)

6 Reliability and validity

The reliability measures the extent to which the results of the study can be reproduced when the research is repeated in the same conditions. The validity is connected to the extent to which results of the study answers the question what it is supposed to answer (Tjora, 2013).

For this study, reliable sources, scientific literature, and self-conducted SWOT-analysis data collection had been used and interpreted.

Complications with data collection due to COVID-19 outbreak, and lack of essential knowledge in many related fields such as law, construction and architecture can lead to inaccuracies in how the data was comprehended.

The aim of the study was to identify barriers for construction materials reuse scaling up, in a way they are seen by different actors of construction sector in Trondheim region, Norway. Many, stakeholders of this region were not a part of the research mainly because of restricted time for thesis writing and because of COVID-19 outbreak. Despite restricted number of participants, the study managed to identify barriers for construction materials reuse scaling up in Trondheim region, and many of identified barriers coincide with barriers that were identified on the national level in Asplan Viak report. Recommendations on how to overcome these barriers were developed based on literature review.

7 Conclusion

In this thesis, challenges/barriers for construction materials reuse scaling up in Trondheim region (Norway) were identified through collection of data from different actors. All barriers were classified on categories, such as quality of used materials, technological challenges, economics, traceability, responsibilities, technical requirements, legal issues, environmental aspects, reused materials market development and linear thinking. The study showed that different actors are focused on different barriers. The main barriers according to SWOT-analysis are related to quality of secondary materials, legal issues, traceability, technological challenges, underdeveloped market for materials reuse, responsibility issues and lack of expertise and examples in reuse projects. As an outcome of analysis of identified challenges/barriers, recommendations that can be used by different actors, were proposed. The proposed recommendations were developed based literature review presented it theoretical part of this paper. Most of those identified challenges/barriers can be also relevant for other regions, because similar barriers were identified in other reports on national and the EU levels. The study showed that challenges related to quality of materials which are result of lack of documents, hazardous content, multi-material content and capacity loose, can be mitigated by such measures as: use of less complex materials, implementation of design for reuse, lean manufacturing, digitalization, BIM, increased traceability, performance of pre-demolition audits and selective demolition, and development and standardization of methodology for testing and re-certification. In addition, legal issues with construction materials reuse due to lack of regulations and standards designed for materials reuse and purchasing of such materials can be mitigated through development of separate regulations for documentation and purchasing of used and new materials. Traceability challenges related to the absence of original documentation, which describes performance properties of materials, and lack of standards and tools for re-certification of used materials can be mitigated by introduction of materials passports, which contain details of the materials and components in construction products and allow maintenance, recovery, reuse, and recycling potential for construction materials and products, and implementation of BIM. Technological challenges related to time-consuming and expensive process of demolition and material recovery can be mitigated by development of new technologies and business models that will be focused on demolition for reuse (design for disassembly); performance of good technical control procedures for materials and products, during use phase; and support of innovations and start-ups that will facilitate development of technologies for materials reuse improvement. Challenges of underdeveloped market for materials reuse caused by lack of market development and infrastructure for materials reuse realization and matching of supply and demand of used materials can be mitigated by development of industrial symbiosis; development of mechanisms that match supply and demand linked to traceability mechanisms; implementation of just in time concept; development of material (waste) exchanges/reuse platforms; and provision of appropriate access to storage and logistics for reused materials. Responsibility challenges caused by unclear role of different actors (no documentation, certification, and guarantee) can be mitigated by introduction of extended product responsibility for construction products.

All the actions, presented above in Table 7, can lead to effectivization of construction materials use, reduction of environmental footprint of construction sector, economic and social benefits. The research showed that the introduction of most of reuse solutions happens on the design/construction and end of life phases. This means that suggested actions can improve materials reuse in Trondheim region both in a short and long term. For instance, selective demolition can lead to an immediate effect on the production of the pure fractions for reuse. Use of a high percentage of reusable elements in high-grade products prevents downcycling. The concept of design for disassembly, influences the end of life phase of building lifecycle. The study showed that the design phase is very important phase for enabling reuse in future through material selection and choice of solutions. Therefore, it is crucial that builders, property managers and architects think circularly from the start of a building or renovation project to realize the potential for circularity. Buildings must therefore be designed in such a way that the materials can be dismantled and reused. In addition, increased reuse requires stable access to reused materials and increased insight into the quality, properties, and possible content of environmental toxins. Today, it can be difficult to provide documentation, which can ensure that existing materials in buildings meet technical requirements in accordance with the regulations. This leads to limited possibilities of reuse. That is why digital platforms for collection and sharing of information on documentation should be used in new projects.

However, obtaining results from most of those suggested actions can take long time. Several decades delay in obtaining measurable benefits from circular economy and materials reuse measures implementation may discourage stakeholders from acting for scaling up construction materials reuse. Thus, governmental measures can play a crucial role by providing economic support for actions that brings long-term environmental benefits from circular economy and materials reuse. However, in most of the cases, the economical price of the solution is considerable argument for action uptake. “The market acceptance of products produced using waste as an input material will only be assured when production costs are lower than for virgin materials” (Wahlström et al., 2020). The transportation distances for reuse and construction materials play an important role too, especially in cases where raw materials are readily available near the end user.

Collaboration and information exchange between different stakeholders and focus of investors and designers on longer-term view with careful mapping of the past, current, and future construction material, and component use, are required. Incentives and tools, which make possible for investors to receive a financial return on those decisions that affect not only the leasing and selling of spaces and properties, but also their repurpose and end-of-life usage, must be developed and used on regular basis. Moreover, new circular business models are needed to increase effective assets use and encourage more use of reusable components, materials and resources (Arup, 2016).

8 Future research

The topic of materials reuse in construction sector is a novel one. The system and market are not developed to an effectively functioning extend. There is no guidance for construction sector actors for how to effectively operate in construction economy environment, and absence of documentation, which can provide information on quality of used materials, limits possibilities of materials reuse. That is why during personal communication with research participants the following suggestions for future research were formulated:

- Effective approach for providing enough information to potential users (buyers) of used materials to ensure that it is safe to use those materials in cases of absence of original documentation.
- Development and standardization of methodology for testing and re-certification of used materials. Proper test methods for different used materials, which will consider properties of different materials, must be developed. How different materials should be tested and who is responsible for ensuring quality of used materials?
- Providing of documentation for used materials that can provide similar information as new materials documentation does.

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