Abstract

Climate change, waste, pollution, and the overconsumption of the earth's limited resources are real threats. To solve these big problems, an innovative idea is needed. In line with the United Nations goals for sustainable development, the concept of circular economy (CE) has gained attraction as an alternative to the current linear economy (LE) "take-make-use-dispose"-model to reduce GHG emissions from buildings and mitigate climate change. Reuse of building materials and products is a key part of this concept, where the goal is to preserve resources and their value within the economy by closing material loops. In the Norwegian construction industry (BAE), many studies show that the reuse can help reduce the amount of waste and GHG emissions from the industry. But it is still limited to a small number of pilot projects.

This thesis aims to investigate which building materials and products can be suitable for reuse from a sustainability perspective. As well as, demonstrate the potential to create a more resource-efficient and environmentally friendly construction industry. For that to be the case, it must be considered a sustainable solution and there must be a potential for creating a market of a certain size. This research will act as a guideline for rehabilitation and fit-out projects with a focus on reuse as a sustainability assessment method. Both qualitative and quantitive data were used to examine the selected case study projects. In total, a literature study, a document analysis including interviews with industry representatives, and finally a comparative environmental analysis of reused building materials and -components compared to new products in two of FutureBuilt pilot projects; Kristian August gate 13 and Kristian August gate 23 in Oslo were performed. The third pilot project, Skur 38, was excluded from this study due to a lack of data acquisition and the use of a different GHG calculation methodology.

The results of the comparative analysis per building parts analysis indicate that greenhouse gas emissions can be reduced by the use of reused material by 70% and 83% from the production and replacement phases for KA13 and KA23 respectively. Among the comparison analysis per material/product, the most significant reductions were scored by the steel and concrete categories. The following material categories were further analyzed in detail: Steel, Hollow-core slabs, windows and doors, brick stone, and facade panels. From the production phase together with the replacement of the building components, all the products provided between 78% and 98% savings compared to a new alternative. In this sense, load-bearing materials, such as steel and concrete, are examples of materials that can have good effects and are considered suitable for reuse to a large extent.

The document analysis has revealed significant challenges in the development of the reuse market. Limited information about the existing building stock also complicates the understanding of the present and future potential for reuse. However, it is still seen that there are sufficient quantities of analyzed material for scaling up the market. In terms of scaling the market, prioritizing certain materials and products will most likely be favorable for establishing safe and efficient solutions for logistics, testing, and re-documentation. The potential for reusing several products and materials is evaluated throughout this study. By focusing on reuse in the planning phase of projects, design for disassembly (DFD), and adaptability, the future potential of the reuse market may be significant. On the way to the reuse-market development, FutureBuilt is improving its circular building criteria to comply with BREEAM-NOR v6.0, and the Green Building alliance included Futurebuilt criteria on their exemplary rating level in their manual v.06. In this study, five corresponding parameters were specified; material efficiency, material reuse, GHG emission calculation, resource utilization, and waste volume.

Sammendrag

Klimaendringer, avfall, forurensning og overforbruk av jordens begrensede ressurser er reelle trusler. For å løse disse store problemene trengs det en innovativ idé. I tråd med FNs mål for bærekraftig utvikling, har konseptet sirkulær økonomi (CE) fått tiltrekning som et alternativ til dagens lineære økonomi (LE) "take-make-use-dispose"-modell for å redusere klimagassutslipp fra bygninger og dempe klimaendringene. Ombruk av byggematerialer og -komponenter er en sentral del av dette konseptet, der målet er å bevare ressursene og deres verdi i et sirkulært kretsløp. I den norske byggebransjen (BAE) viser mange studier at gjenbruk kan bidra til å redusere avfallsmengde og klimagassutslipp fra industrien. Men disse studiene er fortsatt begrenset til et lite antall pilotprosjekter.

Denne oppgaven har som mål å undersøke hvilke byggematerialer og produkter som kan egne seg for ombruk fra et bærekraftperspektiv. Samt demonstrere potensialet for å skape en mer ressurseffektiv og miljøvennlig byggenæring. For at det skal være tilfelle, må det tas i betraktning en bærekraftig løsning og det må være et potensial for å skape et marked av en viss størrelse. Denne forskningen skal fungere som rettesnor for rehabiliterings- og innredningsprosjekter med fokus på ombruk som bærekraftig vurderingsmetode. Både kvalitative og kvantitative data ble brukt til å undersøke de utvalgte casestudieprosjektene. Totalt en litteraturstudie, en dokumentanalyse inkludert intervjuer med industrirepresentanter, og til slutt en komparativ miljøanalyse av gjenbrukte byggematerialer og -komponenter sammenlignet med nye produkter i to av FutureBuilt pilotprosjekter; Kristian August gate 13 og Kristian August gate 23 i Oslo ble fremført. Det tredje pilotprosjektet, Skur 38, ble ekskludert fra denne studien på grunn av manglende datainnsamling og bruk av en annen GHG-beregningsmetodikk.

Resultatene av den komparative analysen per bygningsdelsanalyse indikerer at klimagassutslipp kan reduseres ved bruk av gjenbruksmateriale med 70 % og 83 % fra produksjons- og utskiftingsfasene for henholdsvis KA13 og KA23. Blant sammenligningsanalysene per materiale/produkt ble de mest signifikante reduksjonene skåret etter stål- og betongkategoriene. Følgende materialkategorier ble videre analysert i detalj: Stål, Hullplater, vinduer og dører, murstein og fasadeplater. Fra produksjonsfasen sammen med utskifting av bygningskomponentene ga alle produktene mellom 78 % og 98 % besparelser sammenlignet med et nytt alternativ. Slik sett er bærende materialer, som stål og betong, eksempler på materialer som kan ha gode effekter og i stor grad anses som egnet for gjenbruk.

Dokumentanalysen har avdekket betydelige utfordringer i utviklingen av gjenbruksmarkedet. Begrenset informasjon om eksisterende bygningsmasse vanskeliggjør også forståelsen av nåværende og fremtidig potensial for gjenbruk. Imidlertid ser man fortsatt at det er tilstrekkelige mengder analysert materiale for å skalere opp markedet. Når det gjelder skalering av markedet, vil prioritering av enkelte materialer og produkter mest sannsynlig være gunstig for å etablere sikre og effektive løsninger for logistikk, testing og re-dokumentasjon. Potensialet for gjenbruk av flere produkter og materialer er evaluert gjennom denne studien. Ved å fokusere på gjenbruk i planleggingsfasen av prosjekter, design for demontering (DFD), og tilpasningsevne, kan det fremtidige potensialet for gjenbruksmarkedet være betydelig. På vei til utviklingen av gjenbruksmarkedet forbedrer FutureBuilt sine sirkulære bygge kriterier for å overholde BREEAM-NOR v6.0, og Green Building-alliansen inkluderte Futurebuilt-kriterier på deres eksemplariske vurderingsnivå i manualen v.06. I denne studien ble fem tilsvarende parametere spesifisert; materialeffektivitet, materialgjenbruk, GHG-utslippsberegning, ressursutnyttelse og avfallsvolum.

Preface

This master's thesis was prepared in the spring of 2022 and marks the end of the 2-year study program “Sustainable Architecture” in the Faculty of Architecture and Design at the Norwegian University of Science and Technology (NTNU) in Trondheim. The thesis is part of the course AAR4993 M.Sc. in sustainable architecture at the Department of Architecture and Technology. It is awarded a total of 30 credits by the administration of the department.

This master's thesis deals with the reuse of building materials and products. The background for the choice of this topic is the authors' curiosity, commitment to sustainability and the circular built environment, and growing interest in reuse as a theme. It has been very educational and interesting to work with such a current topic, which has opened the opportunity to meet and talk to many committed and skilled industry professionals.

Many deserve a big thank you for contributing to the project. First, I would like to thank everyone who contributed to the interviews, including SINTEF's senior research scientist, Selamawit Mamo Fufa, and Pasi Aalto, the center director for NTNU Wood, who put me in the right way with the research design and further thesis development. I would also like to thank FutureBuilt for the great cooperation, and especially my co-supervisor, Erlend Seilskjær, who has given me the access and the opportunity to work with the case projects Kristian August Gate 13, and Kristian August Gate 23. Furthermore, most of this thesis is written in the lobby level of the case study project KA13 which gives great help in the work and also contributed to a great connection with the Green Building Alliance, who are also a tenant in the same building, especially, Sigri Heen, that I would like to thank her for great efforts and help to get a better understanding to BREEAM-NOR manual v6.0. Julie Sandnes Galaaen from Multiconsult has also given good input to the environmental analysis.

I am also grateful for all the help I have received from Tommy Kleiven, my supervisor at the faculty, who has followed the work throughout the project period. Inger Andresen and Patricia Schneider-Marin have also been a great help in connection with the thesis development and the start of the master's thesis. Finally, a big thank you also goes to my lovely wife and sweet daughters. Another big thank you to my friend, Dara Ibrahim, who has supported me through an intensive semester and helped me with proofreading.

Happy reading!!

Oslo, June 07, 2022

Sameh Elias Rbahia

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Glossary

Adaptability:	Collective concept of generality, flexibility, or elasticity (Leland, 2008).
As-built documentation ("As-built"):	Describes the building's structure through drawings and detailed information, and must be updated along the way for changes in the construction process (MIM, 2017).
Construction product:	All products that are to be built permanently into a building and that have an impact on the basic building's basic properties and services (SINTEF Building Research, 2016). Furniture is not considered a building material (Sunde et al., 2020).
Construction waste:	A collective term for all of the waste generated from new construction, rehabilitation, and demolition of buildings (Nordby and Wærner, 2017).
Downcycling:	Recycling, where the resulting product is considered to have lower-quality or value than the original product (Leland, 2008).
Design for disassembly:	The concept of design for disassembly and reuse (DfD) is based on materials and solutions being designed so that it is possible to take them apart (Leland, 2008).
Elasticity:	The ability of a building to expand or reduce the size of areas within a given geometry (Multiconsult and Building Environment, 2008).
Energy recovery:	Incineration of waste with the utilization of energy (Nordby and Wærner, 2017).
Environmentally justifiable service life:	The service life justifies environmental impacts added to produce a material (Nordby, 2011).
Flexibility:	Ability to change the layout of buildings (Multiconsult and the Building Environment, 2008).
Functional service life:	The time the building or part of the building fulfills the assumed planned function (MIM, 2017).
Generality:	Ability to change the function of a building without major interventions and costs (Multiconsult and the Building Environment, 2008).
Landfill:	A permanent disposal site for waste when depositing the waste on or under the ground (The Waste Regulations §9-3, 2004).
Life Cycle Assessment (LCA):	Systematic assessment of the environmental and resource impact of materials, products, or services

	throughout all or parts of the life cycle (SINTEF Building Research, 2014a).
Material recycling:	Includes any form of recycling where waste materials are used to produce substances or objects that are not waste (Kilvær et al., 2019).
MOM ("FDV" in Nor.):	Abbreviation for management, operation, and maintenance. Collective term for activities throughout the life of a building (Kilvær et al., 2019).
Recycling:	See definition for re-use and energy recovery.
Rehabilitation:	Restore buildings and components to the original standard without changing function (SINTEF Building Research, 2017).
Renewable and non-renewable resources:	Non-renewable resources are stored in nature and are not renewable, which in theory can run out. Renewable resources have their origin in nature's cycle and can be considered inexhaustible (Brunvoll and Stave, 2007). In reality, many resources are considered to be somewhere in between (Swan label, 2013).
Renovation:	Major building work, includes changes to the building's function, floor plan, or standard (SINTEF Building Research, 2017).
Re-use("Gjenbruk" in Nor.):	Utilization of existing building materials and other residual products by both reuse and recycling (Leland, 2008).
Reuse("Ombruk" in Nor.):	To utilize a product or component again in its original form for the same purpose or new function (Leland, 2008).
Selective demolition (Disassembly):	A form of demolition work where materials and building parts are dismantled during picking, and in practice often carried out as a reverse construction process (Norsas, 1999).
Technical service life:	Service life which associated with the technical durability of a component or building (Leland, 2008).
Upcycling:	Processes where the result is materials of higher quality than the original product (Nordby, 2009).

1 Introduction

1.1 Background

This year's Emission Gap report, prepared by the UN Climate Panel, states that too little is being done to reverse climate change and that major disruptions are necessary for the goals set in the Paris Agreement to continue to be achievable (UNEP, 2019). The world's resources are consumed at a pace that puts great pressure on ecosystems. Unfortunately, environmental investments are often downgraded in today's capitalist society because the effects are only visible far into the future. But if changes do not happen, large costs and consequences will have to be paid for by future generations (Bakshi, 2018).

The construction industry, which is a major consumer of resources and energy, plays an important role in creating change (UNEP and IEA, 2018). The consumption in the industry is not only high but enormous amounts of waste are also generated every year (Statistics Norway, 2020b). The resources and efforts invested in the production of building materials are in many cases not utilized sufficiently, and it is found that as many as 95% of building materials are only used once (Statistics Norway, 2021).

The circular economy has emerged as a new and alternative economic model to today's linear "use-and-throw" practice. Reuse is a central part of this way of thinking (Green Building Alliance and Norwegian Real Estate, 2016; Boye, 2019). The Real Estate Sector's roadmap towards 2050 outlines a future industry where circular principles and reuse are central (Green Building Alliance and Norwegian Real Estate, 2016). The Norwegian building and construction industry is responsible for approx. 26% of the total national waste stream and 36% of greenhouse gas emissions. Renovating existing buildings and building a more efficient infrastructure around energy utilization has major environmental benefits (Statistics Norway,2021). The amount of waste from construction, rehabilitation, and demolition further increased by 5.6% from 2018 to 2019. Less than 50% of this waste was recycled (Statistics Norway, 2021), which is below national and EU requirements of 70% reuse, recycling and recovery of non-hazardous materials (European Commission, 2018). Most of the construction waste in Norway consists of non-contaminated and inert materials and could be reused without any health or environmental risks (Statistics Norway, 2021). As things stand today, however, the reuse of building materials is mainly limited to individual pilot projects. This raises the question of why the degree of reuse in the industry is so low?

Reuse as a topic has recently received a great deal of attention in the construction industry. During the autumn of 2019 and until the spring of 2022, a large number of breakfast meetings, seminars, and conferences were held where reuse has been high on the agenda. Reuse is a key principle in the waste hierarchies (LOOP, 2018). It develops material efficiency across all economic sectors and represents the second-best choice after waste prevention to decrease resource consumption and carbon emissions, and divert demolition waste from landfills (Akinade et al., 2017; Rakhshan et al., 2020). A Nordic study states that the reuse of construction components has the potential to reduce resource consumption by 20% in the Nordic construction sector resulting in greenhouse gas emission (GHG) reductions of approximately 900,000 tons of CO_2 equivalents (Høibye and Sand, 2018). At the same time, it can create social and financial benefits for private companies equating to 1.7% of the annual growth rate (Høibye and Sand, 2018). SINTEF[1] has also launched a research project on the same topic that addressed the market prospects for the reuse of building materials and identified important drivers and barriers to future development (Eli Sandberg and Ann K. Kvellheim, 2021). During the period, several very central reports on the topic were published, including an announcement from the Directorate for Building Quality- DiBK.

Among these reports is a socio-economic analysis of measures for resource efficiency in the industry, which concludes that it is currently more profitable to focus on waste minimization rather than reuse (Ibenholt et al., 2020). This is justified by the fact that there are currently major barriers to the implementation of reuse, and that in many cases it is not profitable for the developer. Nevertheless, it is emphasized that reuse can become more profitable in the long run, through the development of the reuse market. It is currently uncertain what such a development might look like, and the question is how much potential there is for an upscaling of the market. There is relatively little demolition per year, but the industry still generates huge amounts of waste. How much of this waste could have been reused, and is it sufficient that it is worth investing in putting recycling practices to a greater extent in the system?

Among the most important driving forces for the implementation of reuse in the construction industry are the environmental savings it will be able to provide, both in the form of a reduced need for increased resource efficiency and reduced greenhouse gas emissions. At the same time, it is not a given that reuse is the best solution for a more sustainable construction industry (Nußholz, Rasmussen, and Milios, 2019). This raises questions about which building materials and products will be worth investing in in the years to come.

The design for disassembly concept (DfD) has been introduced decades ago (Akinade et al., 2017). However, traditional methods of end-of-life building disposal are dominating since modern society rarely designs with material recovery in mind (Guy and Shell, 2002). Construction materials and products hold the potential of mitigating the overall embodied impacts of buildings from the early stages (Rahla et al., 2021). On the other hand, designers, contractors, and other construction actors must act together to define ambitions for material loops.

Key drivers for reuse in the Norwegian building sector are the reduction of GHG emissions and enhanced company image by fulfilling the criteria of sustainability schemes. The latter often combines sustainability and circular economy concepts (Rahla et al., 2021). BREEAM-NOR (Green Building Alliance, 2020) and the Norwegian FutureBuilt criteria for circular buildings (Nordby, 2020) include both reuse and circular economy principles. In addition, national initiatives such as the "National Strategy on Circular Economy" (Ministry of Climate and Environment, 2021), requirements for the assessment of reuse of construction products (DiBK, 2021), and the establishment of digital reuse platforms (Loopfront, 2021; Rehub, 2021) demonstrate the growing interest in circular practices.

Reuse is still in its early stage in Norway. Only a few pilot projects are currently testing reuse solutions and processes. Two of FutureBuilt projects testing the feasibility of reuse in construction projects have recently been completed (FutureBuilt, 2020, 2021). The lessons learned from these projects will play a major role in the improvement and implementation of measures to promote the reuse of construction products and materials.

[1] SINTEF | Stiftelsen for industriell og teknisk forskning. (Building and Infrastructure Research Institute). https://www.sintef.no/

What we can learn from pilot projects and setting specific reuse goals is the most important success factor which should be included in future reuse projects (Sandberg et al., 2022).

1.2 Aim and problem statement

This study is based on the research project REBUS[2] – "Reuse of building materials - a user perspective " which aims to develop knowledge that will enable wider and more efficient implementation of reusable construction products (REBUS, 2020). There is still a lack of research on how to achieve a circular economy in various industries despite a rapidly growing interest in this transition. Although the construction sector is a major source of GHG emissions, it also holds a large potential in terms of material reuse and circularity thinking. The scientific literature on this topic is still limited, especially in the Norwegian context. The current knowledge is mostly in industry reports for practitioners, based on anecdotal experiences. There is a clear need for more and better information on how to make the most sustainable choices when selecting materials suitable for reuse and designing a circular building.

Another obstacle is the lack of reuse-oriented regulation and documentation. Current legislation and assessment methods are overwhelmingly geared toward new materials and products, and a linear economy model. How can reused material safety be evaluated and documented? How can we decide whether it is more sustainable to reuse material or product or to pick a new one? Through the construction process, how can the different stakeholders communicate and collaborate on approaching circularity in the construction sector?

The REBUS project has five work packages that each address a different aspect of the project objective. Figure 1.1 below shows how the work packages relate to and interact with each other :

1. *User requirement*: analyze user awareness, knowledge, needs, and social practice to find solutions and create a knowledge platform
2. *assessment of construction products for reuse*: Identify best methods for assessing both technical performance and content of hazardous substances in construction products or components that are considered for reuse.
3. *Life Cycle sustainability assessment*: Identify how existing evaluation and labeling methods can be developed for communicating reusable materials from a life-cycle perspective.
4. *Pilot testing and toolbox*: Co-produce implementation of practical knowledge of assessed methods and solutions through pilot projects.
5. *Networking and procurement*: Develop network strategies and recommendations for incitements through procurement and regulations.

The framework of the project is a series of interviews with different groups of actors from the Norwegian construction industry to identify barriers and success factors for reuse as experienced by different experts and professions, the project will continue until December 2024 (REBUS, 2020).

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[2] REBUS is a research project financed by the research Council of Norway through MILJØFORSK program. The project started in January 2020 and will continue until December 2024. The project is interdisciplinary collaboration between architects, engineers and environmental psychologists from SINTEF AS and Inland Norway University of Applied Science together with Boligbygg Oslo KF, FutureBuilt, and Resirqel AS.

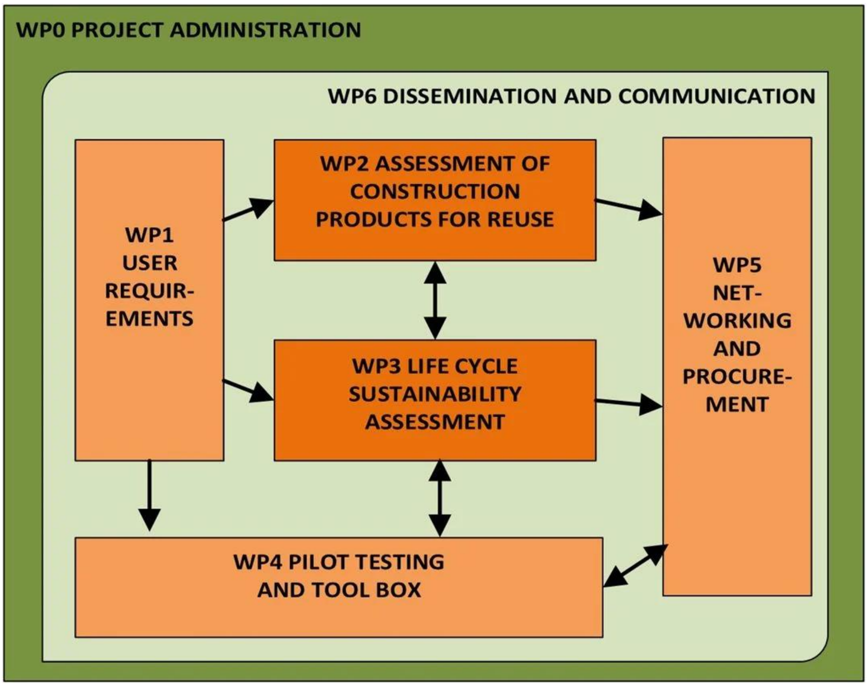


Figure 1.1: REBUS work package structure
(REBUS ,2020)

The ongoing REBUS project identified barriers and drivers to the reuse of construction products, as well as the analysis of perceptions and reflections of different actors adds a new level to studying the adoption of reuse in the Norwegian building sector (Knoth et al. 2022). In the same line, several studies have identified a range of sectoral, financial, regulatory, and cultural factors affecting material reuse in the building sector (Camacho-Otero et al., 2018; Debacker, Manshoven & Denis, 2016; Dunant et al., 2017; Hart et al., 2019; Nordby, 2019) showing that addressing reuse barriers requires a holistic approach (Rakhshan et al., 2020). Based on this, this research was defined, to gain a deeper understanding of pre-studies and competence within various aspects of reuse as a ground before working on the master's thesis. Findings in the pre-studies and projects, thus, have contributed to forming a basis for preparing the problem in this thesis.

The overall aim of this research report is to provide a comprehensive picture of the environmental significance of the reuse of building materials and products. As well as increase the pace of renovation of our existing buildings if we are to achieve the climate goals, and promote circularity as a new way of thinking. The purpose of this study is to investigate and shed light on major environmental benefits and key aspects that can contribute to an understanding of whether it is worth investing in the reuse of building materials, to create a more resource-efficient and environmentally friendly construction industry. For that to be the case, it must be considered a sustainable solution and there must be a potential for creating a market of a certain size.

Based all over, it has been chosen in this study to answer the following question:

"Which *building materials and products can be suitable for reuse from an environmental perspective and what is the potential to promote the circular reuse of materials and scaling up the reuse market"*

The task is relatively two-part defined, but both parts of the problem are considered central for reuse to have a lasting foothold in the Norwegian construction industry. The problem is so complex that it is considered necessary to divide it into some selected research questions:

01 Which building materials and products are suitable to reuse?

02 What environmental effects -CO2 savings- do the reuse of materials and products have compared to the use of new solutions?

03 What development is it likely that the reuse market will have in the years to come?

04 How do FutureBuilt circular building criteria comply with BREEAM-NOR v.06 to identify circulatory indicators for building materials and products?

The research questions will build on and contribute to answering the problem. In this study, it is chosen to focus mainly on research questions 01 and 02, while 03 and 04 will be discussed only under the discussion chapter.

1.3 Scope and delimitations

The task is defined relatively broadly, and there are many different ways to approach the problem. The thesis focus on the reuse potential of building materials and products. The research questions have helped to limit and define which aspects it has been desirable to go into more depth. For instance, the availability of reusable materials in the existing building stock is emphasized as central to an upscaling of the reuse market, when formulating the research questions. However, many aspects are considered central to gaining an understanding of the complexity and scope of the topic, so it has also been chosen to shed light on some aspects such as mapping of the reuse materials and relative environmental effects such as CO2 emission savings on a more general level. While the economical and social aspects of the reuse are excluded from this study.

In connection with the mapping of reuse potential associated with materials and products from existing buildings, it has been chosen to take as a starting point professional market in Oslo. This has been chosen as Oslo is a large and centralized market with high construction, demolition, and rehabilitation activity, and is considered to be able to provide a good picture of possible quantities. It has also been chosen to be based on commercial buildings based on findings from the previous studies, which indicates that many believe that this segment, and especially office buildings, has the greatest potential for reuse in an industrial and professional context.

In the work of assessing the environmental effects of reusable materials compared with a new alternative, a comparative life cycle assessment has been carried out on selected materials/products in case study projects "Kristian Augusts gate 13" (KA13) and "Kristian Augusts gate 23" (KA23). The third case study project "Skur 38" was excluded from this study due to the lack of data acquisition and the use of different GHG emission calculation methods. Furthermore, it has been chosen to prioritize assessing greenhouse gas emissions in the form of CO2 equivalents from the processes, rather than other environmental impacts. This has been chosen, as it is the most common effect category used in such analyzes, and as the work with the analysis has been time-consuming. It was initially planned to assess the social and financial aspects of the reusable materials in the case projects, but for the same reason, these were also excluded from the scope.

The thesis is written over a limited period of five months, and it has thus been necessary to set some boundaries. The time limit has, among other things, set guidelines for the number of aspects that have been practically possible to include. During the project period, the Corona epidemic has also been ongoing, which has affected the work by the fact that information gathering has taken longer. Major changes in the construction industry and business in general, as a result of, among other things, digitalization and the corona epidemic, could lead to changes in the needs associated with commercial buildings. This could have an impact on research question no. 3 and 4, among other things through more people choosing home offices as an alternative. However, this has not been emphasized, as the effect is currently too early to say anything about, and it is assumed that it will not have a major impact on the reuse market. Thus, thesis questions 3 and 4 are chosen to be discussed only under the discussion section.

An important aspect of the research design has been that a lot of relevant work is underway related to reuse in the construction industry. Keeping up to date on the news picture and relevant reports that are published has therefore been important. At the same time, it became necessary to put a stop to the collection of information towards the end of the project period, which means that there may be updates and news that have not been included.

1.4 Outline of the research

The design of the thesis is based on a main scientific structure. The outline is intended to give the content a logical context and ensure an overall flow in the text. See Table 1.1 for an overview of the design of the assignment. Finally, there is an in-depth reference list, as well as appendices that are referred to throughout the text.

Table 1.1: Overview of the research structure and content in each section

	Section	Content
1	Introduction	This includes the background for the research, choice of the problem statement, and presentation of relevant research questions. The scope of the task and current limitations that have been made will also be explained.
2	Theoretical background	This chapter reviews the necessary theory related to the reuse of building materials and life cycle analysis.
3	Methodology	The method chapter describes which methods have been chosen and how they help to answer the problem in the thesis. The choice of method is also evaluated.
4	Case Studies	Here, the chosen case projects are generally presented.
5	Results	This chapter presents the study's findings and results, related to the potential for upscaling the reuse market, by findings from the analysis, as well as the environmental aspect of reuse.
6	Discussion	In this chapter, the theory and findings presented in the results chapter are discussed based on the research questions.
7	Conclusion	The conclusion summarizes the content of the thesis and explains how the overall problem is answered. Furthermore, recommendations have been made for aspects that are considered interesting for research in future work.

2 Theoretical background

2.1 Climate crisis and sustainable development demand

Global trends related to increased economic activity, population growth, and globalization have led to a sharp increase in human impact on the planet in the last century (Bakshi, 2019). Today's linear consumption pattern means that resource consumption increases in line with people's welfare levels and economic activity (IRP[3], 2017). Many of nature's resources are now characterized by overconsumption, ecosystems are under pressure and there is a drastic decline in biological diversity (Bakshi, 2019).

Human activity has also led to a sharp increase in greenhouse gas emissions, and the climate crisis with global warming is now one of the greatest challenges of our time. Drastic shifts and rapid changes are required to avoid or reduce the extent of the serious consequences that temperature changes can have for both nature and humans (IPCC, 2018). The UN Climate Panel emphasizes, depending on the magnitude of the temperature changes, that it will lead to challenges such as increased water shortages, reduced food production, extreme weather, and global sea-level rise. Such consequences will affect and destroy the living conditions and livelihoods of countless people, and many millions will end up as climate refugees (Norwegian Environment Agency, 2020).

2.1.1 Sustainable development

There is broad agreement that this development is not sustainable, and that it is necessary to create a more "sustainable development". The term was first introduced by the Brundtland Commission in 1987 and is defined by the UN as a "development that meets the needs of today without destroying the opportunities for future generations to have their needs met" (UNEP, 2019). The UN's sustainability goals have been prepared as the world's joint work plan to ensure sustainable development. In this lies the social, economic, and environmental aspects, and an understanding that the connection between these pillars is crucial for sustainability. The business community, including the construction industry, has a significant impact on Norway's contribution to achieving these goals (Norwegian Real Estate, 2019). It is worth noting that sustainability goals 11, 12, 13, and 17 are particularly central in connection with the topic of the reuse of building materials. See figure 2.1.

In the effort to limit global warming to 1.5º or a maximum of 2º degrees, 195 countries, including Norway, have through the Paris Agreement committed to reducing their greenhouse gas emissions (UNEP, 2019). Despite international goals and commitments, the temperature has now increased by 1.1º degrees and the current trend is towards an increase of 3.2º degrees by 2100. According to the UN Emissions Gap Report for 2019, rapid changes are required for the 1.5º degree goal to be possible to achieve. They claim that the member countries' action plans are far from ambitious enough and that the necessary global emissions cuts per year will be higher with each passing year (UNEP, 2019).

[3] International resource panel. https://www.resourcepanel.org/

Figure 2.1: The UN's sustainable development goals (UN-SDGs, 2019)

Norway has therefore this year raised its emission targets for 2030 from 40% to between 50% and 55%, compared with 1990 levels (Ministry of Climate and Environmental Protection, 2020). A cooperation agreement has also been entered into with the EU on joint achievement so that Norway is legally obliged to comply with the EU's climate regulations (Ministry of Climate and Environmental Protection, 2019; 2020a).

2.1.2 Circular economy on the rise

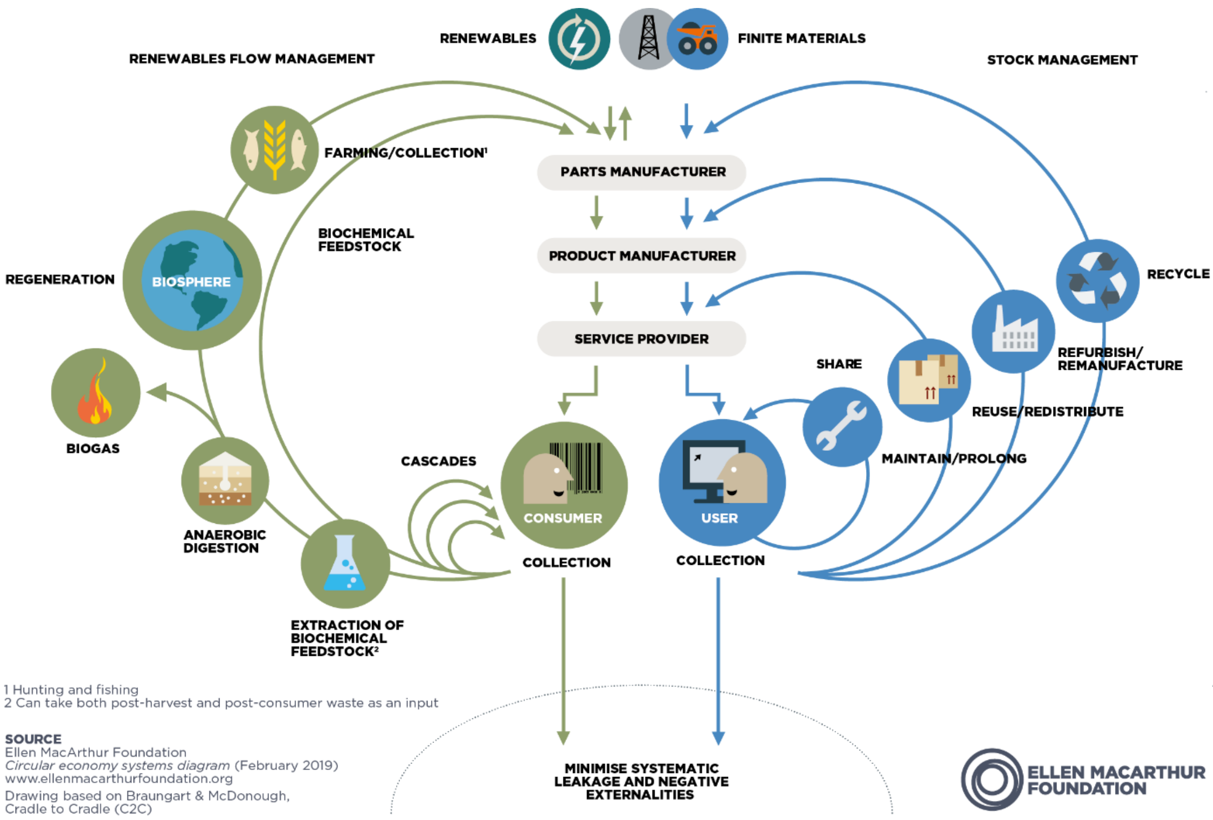


Figure 2.2: Diagram of flows within the circular economy (Ellen McArthur Foundation, 2018)

To ensure sustainable development and achievement of the UN's sustainability goals, should the society's dependency on welfare and economic growth be disconnected from resource use, so that greenhouse gas emissions and resource use can be reduced regardless of welfare levels and economy (IRP, 2017; Bakshi, 2019). To achieve this, many believe that today's linear economy must be replaced by a circular way of thinking (IRP, 2017; Moum, Skaar and Midthun, 2017). UNEP (2019) also claims that it is necessary to decouple economic growth from resource consumption to achieve the UN's sustainability goals.

The circular economy has thus emerged as an alternative economic model to the linear "use-and-throw" economy, which as of today is largely applicable, including in the construction industry (Moum, Skaar and Midthun, 2017). The circular economy is about preserving products for as long as possible and reducing the need for extraction of virgin resources by managing the resources in a circular cycle (Ellen McArthur Foundation, 2018; Geissdoerfer et al., 2017). It is an economy where waste is considered a future resource, and reuse, recycling, and repair are central (Green Building Alliance and Norwegian Real Estate, 2016; Boye, 2019). Figure 2.2 shows the diagram of flows within the circular economy. A shift to a circular economy entails a major transformation in many sectors, and innovation in terms of business models and resource management (Boye, 2019).

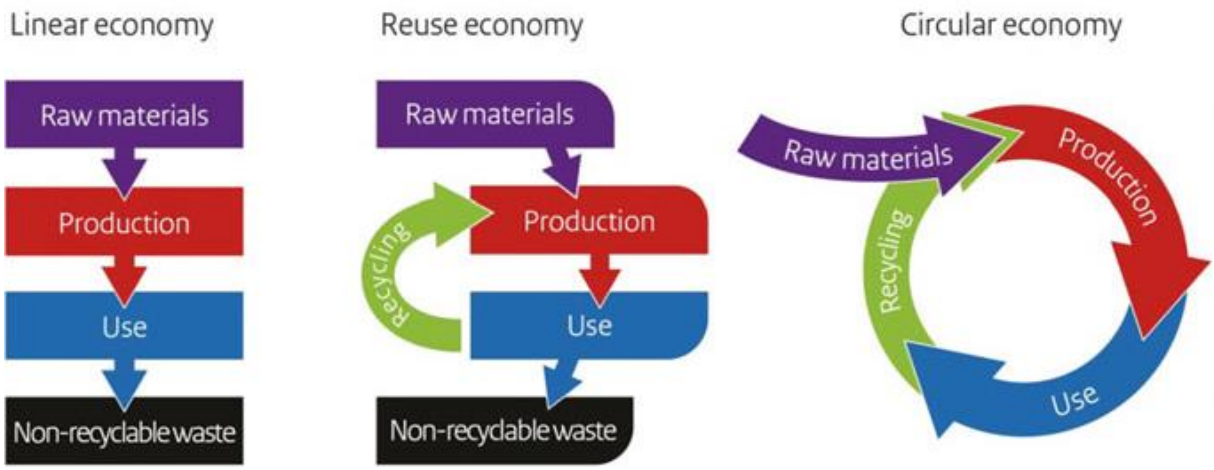


Figure 2.3: Illustration of linear and circular economy based on (Boye, 2019).

The EU has since 2015 been committed to implementing a circular shift in Europe and has recently presented a new action plan for the circular economy (European Commission, 2015). In this, development has been announced in the framework for production in return for it being more profitable to produce products with longer service life, and for it to be facilitated to a greater extent for reuse and recycling. Several countries are well underway the transition to a circular economy and the Norwegian government has, among other things, decided that we will be a pioneer in the circular economy (Boye, 2019; the Prime Minister's Office, 2019). According to the plan, a national strategy for the circular economy will be presented towards the end of 2020 (Ministry of Climate and the Environment, 2020b).

2.1.3 The environmental impact of the construction industry

The construction industry plays an important role in achieving the climate goals because there are major direct and indirect environmental impacts related to many of the activities in the industry (Bramslev, 2018). Globally, the construction industry is responsible for around 40% of all energy consumption and greenhouse gas emissions, in addition to 50% of raw material extraction each year (UNEP & IEA, 2018; Circle Economy et al., 2018).

Although many measures have been taken to pull the industry in a "greener" direction, an annual status report, prepared by the UN Environment Program and the International Energy Agency (IEA), states that the global construction industry's measures to reduce greenhouse gas emissions are stagnating (UNEP & IEA, 2019). In an industry that is traditionally characterized by short-termism and an ever-increasing turnover rate of buildings and building parts, change is important (Nordby, 2009). It is necessary to step up the current efforts for a more sustainable practice, at the same time as there are unforeseen opportunities in the construction industry of the future as the building stock worldwide is expected to double by 2050 (UNEP & IEA, 2019).

On a national basis, it is estimated that the building and construction sector accounts for as much as 15.3% of Norway's total annual greenhouse gas emissions (Asplan Viak, 2019). This also includes contributions from other sectors, as a result of construction activities. Figure 2.4 shows the distribution of emissions.

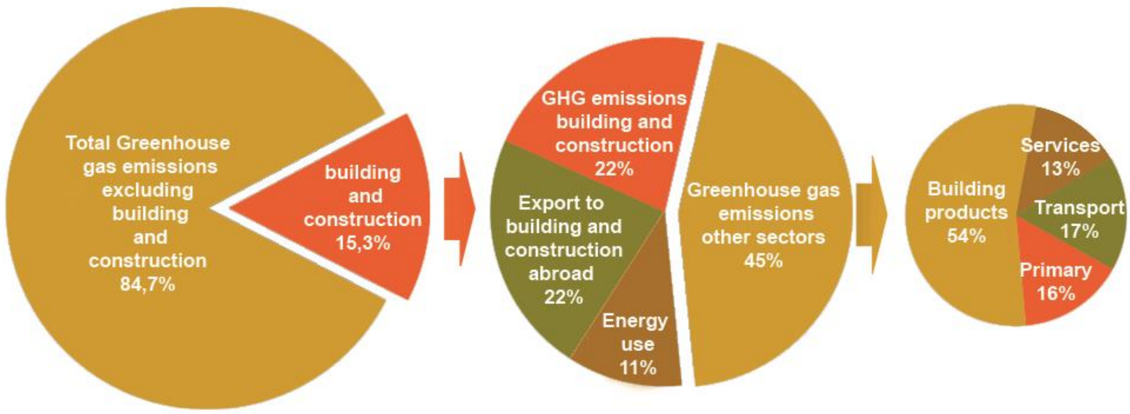


Figure 2.4: The construction sector's share of Norway's GHG emissions (Asplan Viak, 2019).

For many years, the energy needs and emissions related to the use and operation of buildings have been in focus, but as more energy-efficient solutions are developed, the environmental impact associated with the use of materials has also become more central (Asplan Viak, 2018). Extraction, production, transport, and waste management of building materials and technical installations require large input factors of both resources and energy (Fuglseth et al., 2018). As presented in Figure 2.4, building materials are responsible for a significant proportion of emissions in Norway, at the same time as large quantities of building materials are also imported from abroad each year, which are not made visible to the same extent in the statistics (Bramslev, 2018).

Well-thought-out material choices can have a major impact on the industry's carbon footprint, while circular principles increase the opportunities for more efficient use of resources (Green Building Alliance and Norwegian Real Estate, 2016). In line with this development, the question is how the circular ideas can be realized in an industrial construction field where economy, time use, and efficiency are set tight and still «linear» frameworks (Asplan Viak, 2018).

2.1.4 Need for waste reduction and better waste management

Nationally, large amounts of waste are created every year, and waste from building and construction activity makes up a significant part of the total, with up to 25% (Norwegian Environment Agency, 2019b). Norway is obliged to comply with the EU framework directive for waste (Ministry of the Environment, 2013). The directive regulates the handling of waste in general and has in recent years been updated to include more ambitious goals for source sorting, reuse, material recycling, and increased producer responsibility (Wilsgaard, 2018). An important guideline in the regulation is the requirement that at least 70% by weight of all building and construction waste, except for hazardous waste, must be reused or recycled by 2020 (Ministry of Climate and Environment, 2013).

According to Building Technical Regulations[4] (TEK17), on construction sites, there is a requirement for a 60% degree of sorting of all waste, and the sorting can help to provide a starting point for more efficient waste management (Building Technical Regulations, 2017). In general, for waste management, it is recommended to follow the priorities of Norwegian waste policy and the EU framework directive for handling, illustrated through the waste pyramid in Figure 2.4 (LOOP[5], 2018). This hierarchical overview says something about how waste should be handled initially to achieve the best possible utilization of the resources available, and the goal is for the waste to be treated as close to the top of the pyramid as possible. This is beneficial for preserving the energy and resources invested in the extraction and production of new materials and products (Waste Norway, VESAR and Norwegian recycling, 2016).

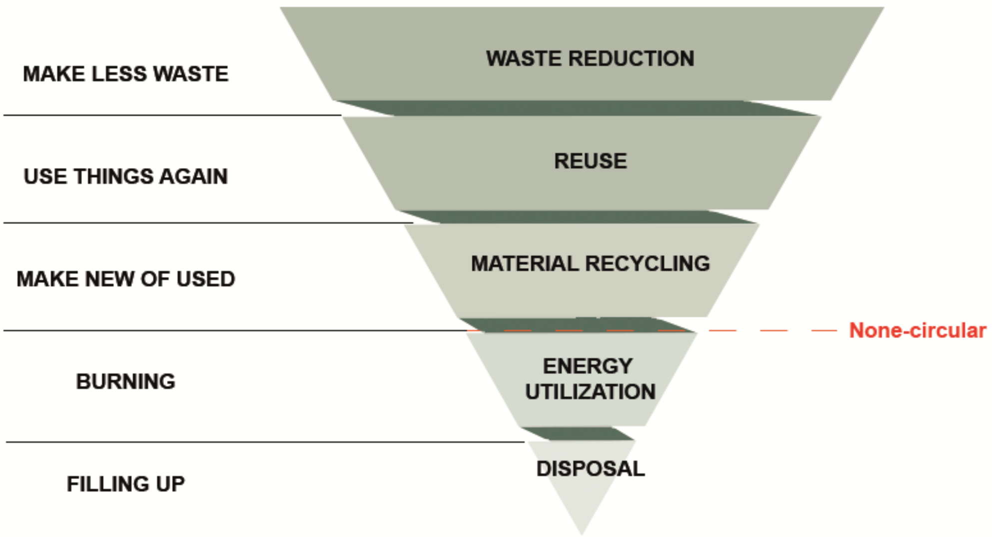


Figure 2.5: Presentation of the waste hierarchy

(LOOP, 2018)

[4] TEK17: The Building technical regulations. https://dibk.no/regelverk/byggteknisk-forskrift-tek17/

[5] LOOP: Foundation for Source Sorting and Recycling. https://loop.no/

There are a total of five different levels for waste management according to the Foundation for Source Sorting and Recycling (LOOP, 2018):

- *Waste reduction*: Ensure that waste does not initially occur as far as possible.
- *Reuse*: As previously explained, it is about using things again and thus extending the life of the products.
- *Material recycling*: Use materials for the manufacture of new products or substances that can be reused.
- *Energy utilization*: Waste is incinerated and the heat energy can be used for district heating and industrial use, at the same time as harmful environmental substances are destroyed (Norwegian Environment Agency, 2019c).
- *Landfill*: Landfill is the lowest level of the pyramid, and is considered a safe final treatment if the other levels in the pyramid are not possible. This is only reserved as a last resort because the landfill produces more greenhouse gas emissions (Norwegian Environment Agency, 2019a).

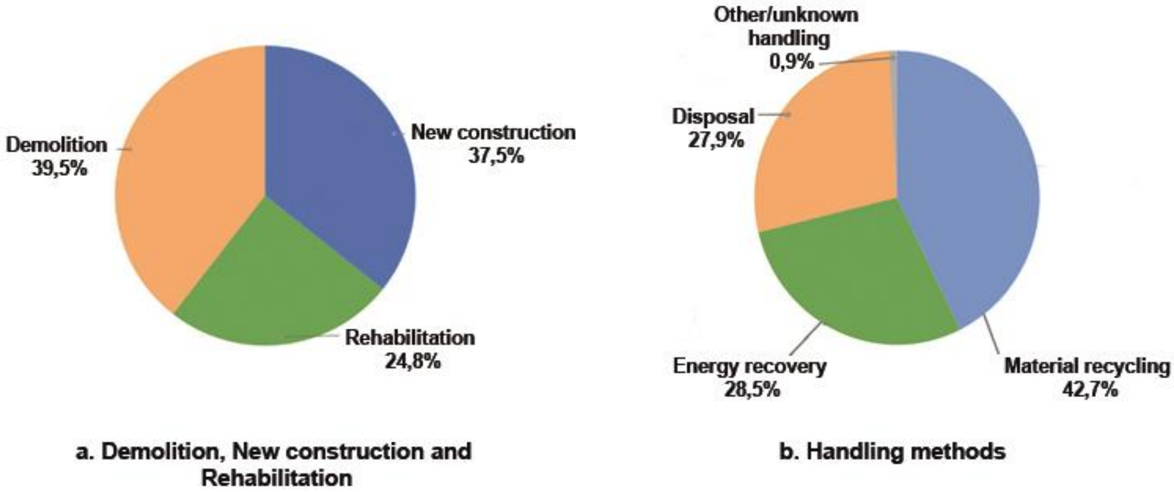


Figure 2.6: Distribution of waste quantities (Statistics Norway, 2020b).

Annually, just over 1.8 million tons of waste is generated, divided into activities from demolition, rehabilitation and new construction (Statistics Norway, 2020b). The waste statistics are considered to have some dark numbers, as Statistics Norway compiles the statistics based on submitted data from waste plans and final reports that are sent to the municipality when applying for the projects' completion certificate (Nordby and Wærner, 2017; Statistics Norway, 2020b). This is not required for minor construction measures, as regulated in TEK17 Regulations §9-6 (Building Technical Regulations, 2017). A report carried out by NOMIKO estimates that the actual amounts of waste are a lot more if one includes everything from construction and demolition activity (Valde, Ottersen and Wormstrand, 2018). In addition to this, there are other activities related to the construction industry that are not included, for example, waste from the production of building materials will instead be regarded as industrial waste (Ibenholt et al., 2020).

The distribution of waste related to new construction, demolition and rehabilitation activities is presented in Figure 2.6a. It is mostly waste from demolition and new construction. Figure 2.6b shows the handling methods of the total amount of waste from 2018. A relatively large proportion is sent to material recycling, around 43%, but this means that it is still too far to reach the intended EU framework directive's target of 70% material recycling and reuse by the end of 2020 (Ministry of the Environment, 2013). Furthermore, a lot is still sent to landfills, around 30%. This type of waste treatment accounts for 28%. It is worth noting that the statistics do not make visible the reuse of materials as treatment.

The material fractions that stand out in the statistics are concrete, brick and other heavier building materials (37%), wood (13%) and asphalt (11%) (Statistics Norway, 2020b; Green Building Alliance and Norsk Eiendom, 2016). Hazardous waste makes up a small part of the total amount of waste, but the proportion has increased sharply in recent years with almost a doubling the amount from 2014 to 2018 (Statistics Norway, 2020b). A report prepared for the Norwegian Environment Agency indicates that the amount of hazardous waste will continue to increase in the years to come (Norwegian Environment Agency, 2019a). There are potentially several reasons for this, including the fact that increased knowledge about environmentally hazardous substances means that several types of products are classified as dangerous.

As waste management is today, there is potential for increasing resource efficiency within the material categories by going up one or more levels in the waste pyramid (Nordby and Wærner, 2017). The handling for some of the larger fractions is presented in Table 2.1. For example, almost all wood is sent for energy recovery, and about 50% of the gypsum waste is landfilled. Chaudhary (2019) believes that relatively large amounts of waste are little polluted. This increase the possibility that the materials could have been used again without special environmental considerations.

Table 2.1: Distribution of waste management for selected material groups in 2018. (Statistics Norway, 2020).

Material Category	Material recycling [%]	Energy recovery [%]	Landfill [%]
Wood	1,7	97,6	0,4
Metal	100	0	0
Gypsum	51,6	0	48,4
Glass	73,7	13,7	6,2
Brick, concrete, and other heavier building materials	58	0	41
Hazardous waste	20,6	20,7	36,3
Mixed waste	0,6	99,4	0

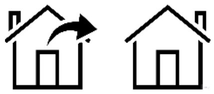
2.2 What is reuse and what does it involve?

Reuse means reusing a product in its original form (Rognlien, 2002; Sørnes et al., 2014). Nordby and Wærner (2017) and Asplan Viak (2018) define the term as: «any operation where products or components that are not waste are reused for the same purpose for which they were made». In this thesis, it has been chosen to include that the product can also be used for new purposes, but with a small degree of adaptation and processing. The terms re-use (gjenbruk) and reuse (ombruk) are often confused with each other, (see the concept descriptions in the Glossary), but reuse (ombruk) is in this thesis considered a collective term for material reuse (Leland, 2008; Sørnes et al., 2014).

Reuse is based on the thinking of a circular economy and constitutes the second-highest level in the waste pyramid. It can be categorized into different forms, as shown in figure 2.7 (Sørnes et al., 2014). There are variations in the legislation that include the different types of reuse. This will be described in subchapter 2.4.

Local reuse: Reuse when upgrading the same building from which the elements are taken. The materials must be moved in order for it to categorized as reuse.

Internal reuse: The reuse -elements are owned by own organization and brought in, to both local reuse and reuse elsewhere.



Reuse elsewhere: Reuse elements are retrieved from other buildings(donor buildings).

External reuse: Sales and purchases reuse elements from other organizations.

Figure 2.7: Different forms of reuse
(Sørnes et al., 2014)

Other key concepts

Upcycling is a useful term for reuse. This means giving materials new value through product development and processing. Depending on how this processing takes place, this can also be included in the concept of reuse (Kilvær et al., 2019). Examples of upcycling can be assembling used windows for multi-glazed windows to achieve regulatory requirements or using compressed and treated ventilation ducts for facade elements (Nielsen et al., 2014). In the opposite sense, downcycling means using single stock parts in products, and often involves decomposition into a product of lower value (Kilvær et al., 2019). An example of this could be crushing concrete to use as a filler. Resirqel also describes this as destructive reuse (Sunde et al., 2019).

Another aspect, which is central to waste minimization and utilization of resources, is the use of surplus materials (Kilvær et al., 2019). Surplus materials can, among other things, occur on construction sites or at building materials retailers and manufacturers, in the form of b-products that are not sold out or cut off. As surplus materials are completely new and usually have all the necessary documentation, this is low-hanging fruit in the work with waste minimization (Ibenholt et al., 2020).

Furthermore, today there is a strong increasing focus on preserving buildings rather than demolishing them (Green Building Alliance, 2019). Preservation of entire buildings through rehabilitation and transformation is of course very central from an environmental perspective and in a circular-economic way of thinking, but in this thesis is not considered directly as reuse. Resirqel writes that "Demolition, rehabilitation and more efficient use of existing buildings is the most valuable way to do it, but where there is no alternative, waste reduction and reuse is an opportunity with great potential" (Kilvær et al., 2019, p 14).

Reuse is not new

Although there is a very low degree of reuse in the industry today, the reuse of building materials is not a new phenomenon. In fact, until the 1960s, there were strong traditions for the reuse and sorting of building materials in Norway (Green Building Alliance, 2019). The materials have traditionally been very expensive, and one could save a lot by using materials such as ceilings, roof constructions, bricks and windows. Old log buildings are often cited as an example of buildings previously being designed in a way that made it possible for elements to be easily dismantled and reused (Leland, 2008; Sørnes et al., 2014). However, this practice has to a small extent been passed on to modern buildings, and few buildings have recently been adapted for new use without extensive alterations (Leland, 2008; Green Building Alliance, 2019).

2.3 The reuse potential of building materials

Several different factors affect whether a building product can be considered reusable or not. What is technically possible to reuse is not necessarily practically feasible or legal (Kilvær et al., 2019; van den Berg, Voordijk, and Adriaanse, 2020). Whether something has the potential to reuse or not is not black and white. It is nuanced. In their master's dissertation, Mynors and Moldekleiv (2017) prepared a flow chart for evaluating the reuse potential of materials. This has been modified to include TEK17 and is shown in Figure 2.8. It is emphasized that it is important to use judgment when using the flow chart, as not all questions are straightforward to answer. In practice, the process will also often take place less successively than the flow diagram presents it (Mynors and Moldekleiv, 2017).

In the literature, the reuse potential of several materials has been discussed (Addis, 2012; Nordby, 2009; Gorgolewski, 2008). Factors such as environmental impact from production, raw material prices and the technical quality of the material, energy consumption, economy, and service life are important in assessing which materials are best suited and should be prioritized from a reuse perspective (Selvig et al., 2020; Leland, 2008; Sørnes et al., 2014).

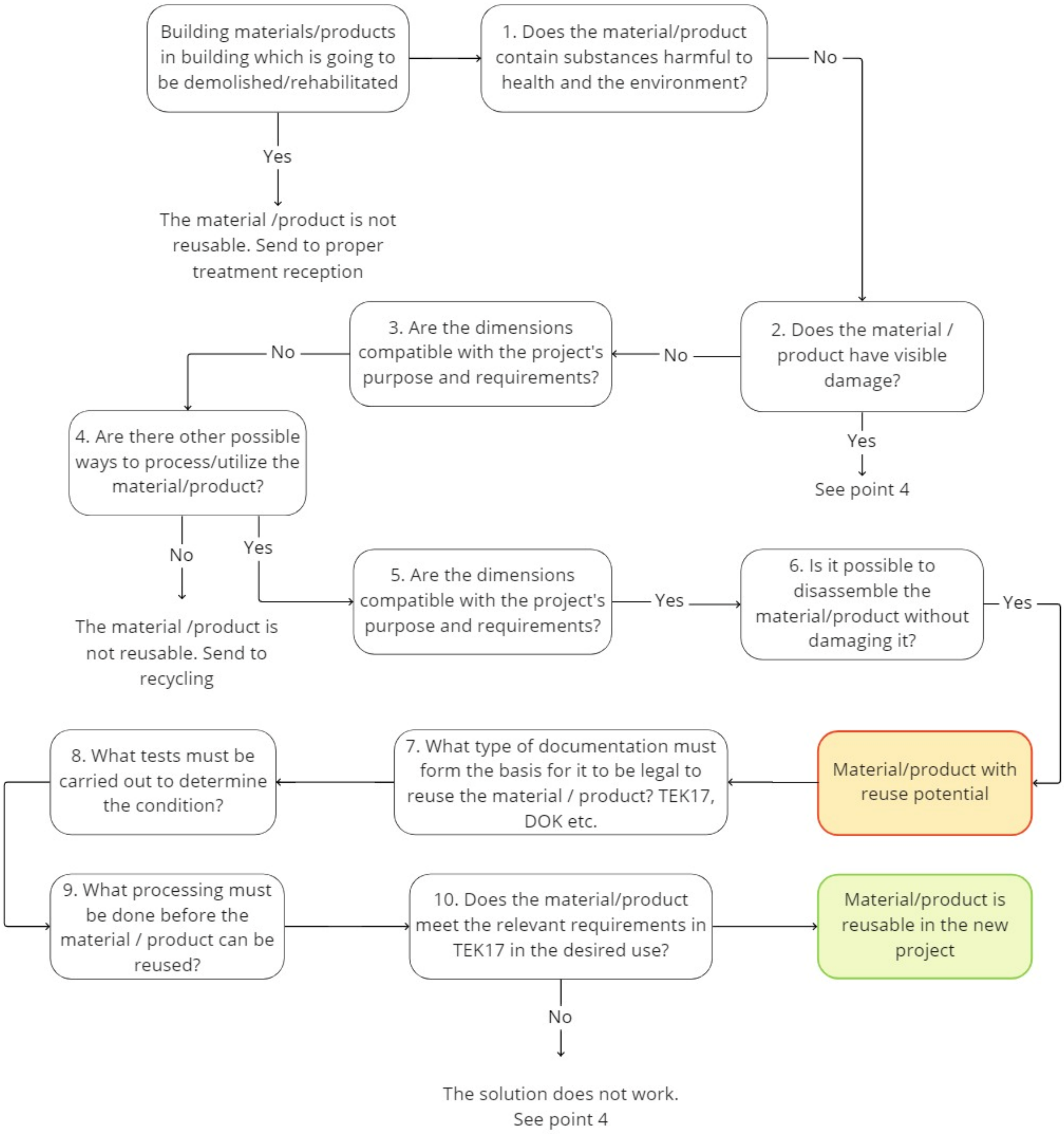


Figure 2.8: Flow chart for assessment of reuse potential self-produced based on (Mynors and Moldekleiv, 2017).

In the project «Nordic Built Component Reuse», an assessment was made of materials based on a selection of nine criteria, see Figure 2.9. The project looked specifically at recycled solutions for different materials, but the categories for evaluation are considered equally central in an assessment of reusable products in general (Nielsen et al., 2014). How well the materials score in the different categories is made visible by how far out in the circle they reach. The outermost line of the gray area indicates values for conventional materials, and the further out in the form, the higher the potential for reuse. The evaluation method takes into account aspects that affect all three aspects of the concept of sustainability.

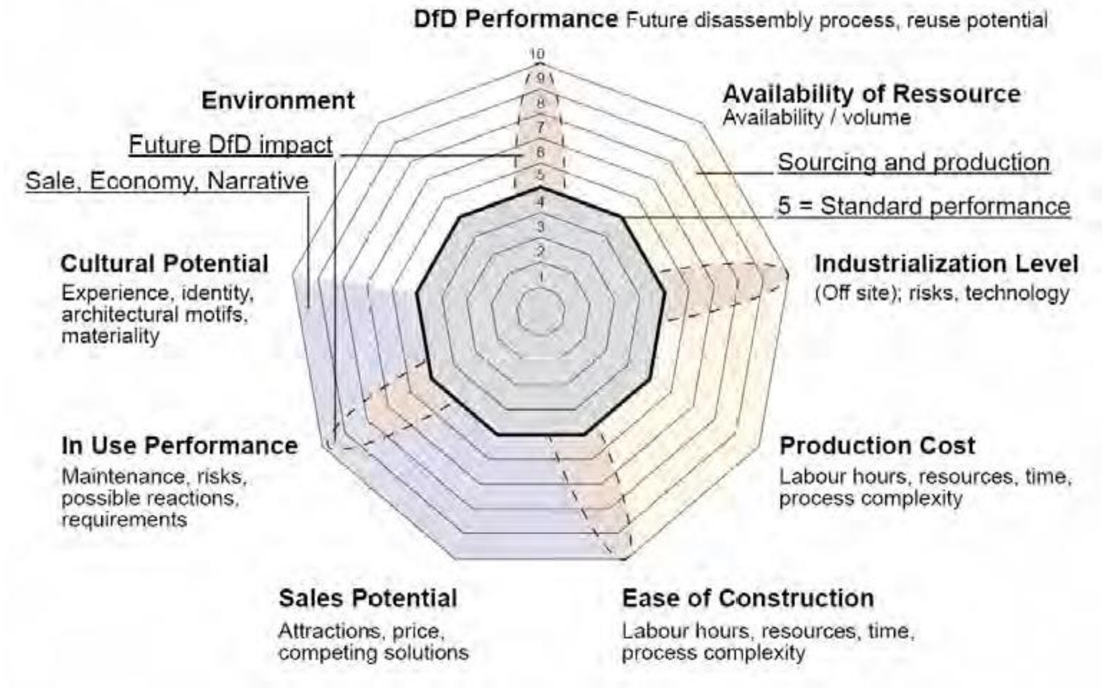


Figure 2.9: Assessment chart for reuse potential (Nielsen et al., 2014)

main value categories – The grey zone in the radar diagram indicates values below conventional performance (5). Other colors: While "Sourcing and production", and "Sale, Economy, Narrative" connect in groups of values, the impact of the DfD performance of concepts affects future cycles of reuse more scattered along with the diagram.

2.3.1 Evaluation of the reuse potential of various materials

The report «Forsvarlig ombruk av byggevarer» or « proper reuse of building materials», prepared by Team Resirqel on behalf of The Directorate for Building Quality (DiBK), systematically reviews which material groups are suitable and the possibilities for reuse with current conditions. Six relevant categories for reuse are highlighted; load-bearing steel, Hollow-core slabs in concrete, brick, window/glass, wood, and materials without documentation requirements. These categories are highlighted based on recommendations from the literature, the author's experience from projects, the necessary energy for extraction and production, as well as materials with a short cycle time despite a long service life (Kilvær et al., 2019). A sufficient volume of the materials in use and the amount of construction waste are also emphasized. As concrete, brick, and wood are particularly prominent in the waste statistics, these material groups will be very relevant to focusing on reducing waste in the industry (Statistics Norway, 2020b).

Based on the categories found in the literature, a general overview is summarized in Table 2.2 of the possibilities and challenges of various materials related to reuse, as well as the impact on the external environment through extraction and procurement.

Table 2.2: Overview of reuse potential of various building materials and products.

Material Category	Environmental impact	Possibilities	Challenges	Current status
Load-bearing Steel	Limited resource, but great potential for repetitive material recycling with satisfactory quality [3] Very energy-intensive in production, but also possible to produce metals with a large proportion of recycled raw material [3;5] In the case of material recycling, steel, and aluminum, respectively provides 80% and 95% savings compared to new production [7] Reuse of structural steel can save up to 96% emissions compared to virgin [8]	Metals are durable with a long service life in proper use [6] Steel and aluminum for load-bearing use can be suitable for reuse. Good possibilities for better connections that simplify disassembly-/assembly [7] Great potential for smaller metal components such as fittings, railings, door handles, hinges, and the like, if they are undamaged and demountable [4;6] Ventilation ducts of steel have proven to be very favorable economically in previous projects [6]	Structural steel must be documented before new use, and significant processing leads to the need for CE-marking. Environmental toxins in the surface treatment of steel can be a barrier [7] Reinforcement steel is subjected to dynamic loads and fatigue, as well as, steel that is manufactured before 1970 is not suitable for reuse (unless there are bolted connections)[7;8]	Assumed as good opportunities for reuse of steel with current regulations. A lot of ongoing work to develop procedures based on standards. CE marking is possible within current regulations if required [7] Example of reuse of structural steel profiles (rolled and hollow) and metal facade panels in KA13 [9]. Ventilation pipes in galvanized steel are also reused in the project [6]
Wood	A renewable source with large access to virgin wood in Norway[1]. Wood is a large part of waste fractions, especially from new buildings [9] Often referred to as climate-neutral due to biogenic carbon uptake in wood, which acts as temporary storage of CO2 limited by the life of the material before combustion or decomposition [3;6]. It is debated, and neutrality depends on whether the wood comes from sustainable forestry or endangered rainforest [1]	Potential in structural timber such as columns, beams, and girders, as well as glulam in I-profiles and wood fiber slats, in addition to whole room modules [7] Exterior / interior cladding and wooden doors can easily be reused, subject to a declaration of performance where applicable. Possible to use undocumented wood for moldings and window frames [2] Wooden fiberboards with intact properties and shape can be reused directly [6]	Must be able to document sufficient quality for use, especially construction timber [2] Careful disassembly and intermediate storage to avoid damage to the wood [7] The cost perspective can make it more economical with virgin wood [6]	Over 99% of wood is currently sent for energy recovery [10] Some initiatives look at how wood can be recycled into new wood products, such as chipboard[10]

Brick	Energy-intensive production with large emissions [2] A large part of the waste statistics [9] Big savings on reuse. Old Bricks has calculated that a brick saves 0.5 kg CO2 eq. compared to the new [11]	Durable material with long service life, in addition to a modular product that is well suited for reuse [2;12] Possible use in non-load-bearing walls inside and in plaster facades [6] Some types of brick (and concrete) roof tiles can easily be reused if there is no damage [7]	Demanding disposal process that makes it uneconomically beneficial in many projects. Particularly challenging if bricks are bricked with cement mortar, rather than lime mortar [2] Documentation requirements and possible incineration for use where load-bearing capacity and frost resistance are important, such as facades and ground bricks. The danger of harmful substances to health and the environment in brick in contact with elastic joints with a high content of PCBs often built btw. 1940-1980 [6]	The reuse of bricks has been tested in several projects in Norway [7] Crushed and used for filling or sent to landfill [3] In Denmark, a quality assurance system has been developed, which is still awaiting approval from the EU [7] In KA13, an approx. of 34 m^3 (40 tons) of reused brick stone has been used as a solution for a firewall facing the neighboring building (Faculty of Law) [9].
Concrete/Hollow-core slabs	Energy-intensive production process with large CO2 emissions, especially due to cement production. It is estimated that 5% of the world's greenhouse gas emissions are due to cement production [4] Concrete reinforcement bars, which increase strength, also contribute to the overall environmental impact, but may also have a recycled proportion of metal [3] Concrete is a large part of the waste fraction, at the same time as it is one of the most used materials [13] Discussed whether the uptake of CO2 through carbonation during its lifetime should be included as a positive environmental contri-bution [14]	Durable material with a long life. Prefabricated concrete elements may be suitable for reuse. Special mention is made of hollow-core slabs [6] Prefabricated elements can be adapted for disassembly by better information and installation of fastening devices [7]	Concrete quality and properties must be documented during testing [7] The natural content of heavy metals must not exceed the limit values, such as the content of PCBs and chromium. It May also contain other harmful substances from paints and other surface treatments [6;16] In-situ concrete and non-reversible joints in existing buildings, such as screeds and end anchors, as well as the lack of fastening points make reuse difficult [7] Must be calculated for processing of almost all concrete hollow-core slabs before reuse [7]	Low direct reuse today. Often recovered by crushing concrete into filling materials or sent to landfill [3] Reuse of hole coverings from the Government Quarter has been tested for reuse in KA13 and the Oslo city emergency hospital (Storbylegevakt) [7] preservation of existing hollow-core slabs in KA23[23] Recently adopted revision of the regulations that increase the limit for hexavalent chromium in concrete. Will prevent automatic disposal and enable reuse/recycling to a greater extent [15]

Windows/Glass	Energy-intensive production with high emissions. Plenty of raw materials from non-renewable sources. Can be recycled easily, but with lower quality [3]	Relatively simple disassembly options based on modules 6;12 It is possible to reuse glass in contexts where the demands are less, such as in an unheated building or interior walls [6]	A large proportion of old windows contain substances that are harmful to the environment, which must be handled in a responsible manner [6] PCBs in sealant in Norwegian windows from 1965-1975, chlorinated paraffin from 1976-1989, pellets from 1990-2005 [17] Requirements for satisfactory, documented technical properties, such as insulated windows and safety windows [6; 7]	Some glass is recycled for use in glass wool insulation [3] Several projects with reused glass in several forms, for example, office fronts, glass facades and windows in KA 13[7] and KA23 [23]
Technical Installation (heating, ventilation and lighting)	Some technical equipment is made of metal, such as steel and aluminum, with very energy-intensive production processes [6]	Ventilation ducts and newer lighting equipment may be relevant for reuse [2] Buildings from 1970-1980 and more recent may have more potential for reuse of ductwork than older buildings [18]	Difficult to get a warranty on new products, usually short lifetimes and a lot of replacement. Can also be difficult to disassemble 2:6 Reuse of ventilation systems may require compromises concerning current requirements for new buildings [18]	In KA13, both radiators and cooling baffles are being reused [9] In KA23, some technical installations were reused internally; pumps, and a snow-smelting plant. Also used-brought items/added items such as air handling units (AHU) [23]
Gypsum	Depends on the proportion of recycled gypsum, but there is relatively little pollution during production. Can have up to 99% recycled gypsum content and can be recycled indefinitely [3]	One of the most widely used building materials. Thoughtful design and careful handling can increase the potential for reuse [2]	Challenging to disassemble for reuse as the plates are porous and easily damaged during disassembly [7] Transporting heavy plaster is costly [2]	Gypsum waste is normally handled by recycling (56%) or landfill (44%) [11] The gypsum waste recycling plant at Holmestrand produces recycled raw material for the production of new gypsum boards [22]
Insulation	Different forms of insulation have different environmental impacts. Glass wool often contains some recycled raw material. Rock wool requires some energy in production, depending on the size or density of the product [3]	Functional service life can be longer if the insulation is installed correctly and protected [3]	Must be in good condition and without damage/wear to enable reuse [2]	Most of the insulation is sent to landfill [2] Some manufacturers have a return scheme to set up recycling for new insulation [19]

Without Documentation	Depending on specific material and product. Materials related to landscape architecture are generally a relatively small proportion of total construction waste [7]	No need for testing or redocumentation that makes it easier to reuse [3] Composite products that can not be divided can be advantageously reused [19] Fixed furnishings and fixtures, as well as windows for other uses (interior/without requirements)[7;21]. Materials for landscape architecture, such as concrete/granite tiles and field bricks [7]	Often aesthetics become a decisive factor in whether reuse is relevant [2;7]	More items on the reuse of brick, concrete/granite tiles, and stone in landscape architecture [7] Reuse of furniture is more widespread, but not very well established and often only within organizations [22] Reuse -brought items/added items in KA23, for example, leftover tiles from KA13 [23]

1. (St. report 45 (2016-2017), 2017)
2. (Leland, 2008)
3. (Hagen, Haupt og Bramslev, 2017)
4. (Asplan Viak, 2018)
5. (Myhre, Widenoja, Kilvær, 2018)
6. (Sørnes *et al.*, 2014)
7. (Kilvær *et al.*, 2019)
8. (Pimentel, Brown og Sansom, 2019)
9. (FutureBuilt, 2020)
10. (The Builder, 2020)
11. (Statistics Norway, 2020a)
12. (Old Bricks, n.d.)
13. (Ibenholt *et al.,* 2020)
14. (Hopkinson *et al*., 2019)
15. (SINTEF Building Research, 2015)
16. (Norwegian Environment Agency, 2019a)
17. (Butera *et al.,* 2016)
18. (SINTEF Building research, 2012; 2018)
19. (Mysen, Aronsen og Johansen, 2014)
20. (Ragn-Sells, n.d.)
21. (Sunde *et al.,* 2019)
22. (Möhring, 2019)
23. (FutureBuilt, 2021)

Upcycling and creative use of materials

Where building materials do not satisfy requirements for further use in their original form, there are opportunities to look at a more alternative use. Such an approach is considered in more detail in the "Nordic Built Component Reuse" project. Among the results from the project was the use of rolled ventilation ducts as metal cladding, floor coverings as facade cladding, and composite window surfaces for integrated glass facades (Nielsen et al., 2014). How these solutions came out in economic and environmental assessments varies (Nielsen et al., 2014). Decorative purposes, furniture and installations are other examples of creative use of building materials, where the requirements for documentation and technical performance are less extensive as the products are no longer considered building materials (Kilvær et al., 2019).

Materials less suitable for reuse

Among material groups that can be categorized as more challenging in the context of reuse are various types of plastic and composite materials that are permanently attached or glued to a substrate, such as laminates, pipes, bathroom tiles and floor coverings (Leland, 2008; Sørnes et al., 2014). Insulation and gypsum are highlighted as materials that in theory can be reused, but with the condition that they are without damage. This is challenging in practice, which may mean that material recycling can be a better alternative (Kilvær et al., 2019; Leland, 2008). Gypsum is particularly relevant, which can have up to 99% recycled gypsum content and can be recycled indefinitely (Hagen, Haupt and

Bramslev, 2017). Other categories that are also suitable for material recycling are concrete and bricks, which can be crushed to aggregate. This is temporarily considered recycling compared with other recycling and reuse solutions (SINTEF Building Research, 2012). Material recycling of metals can in some cases be a better solution for a good result (Myhre, Widenoja and Kilvær, 2018).

2.4 Legislation related to reuse

The legislation is present to ensure proper construction of buildings of good quality, appropriate treatment of waste, and prevention of substances that are harmful to health and the environment. All buildings, regardless of whether reused materials or new ones are used, must therefore meet certain quality requirements (DiBK, 2018). The literature points out that parts of current regulations create challenges for the implementation of reuse projects (Asplan Viak, 2018; Kilvær et al., 2019). Some key parts of the regulations will be reviewed in this chapter.

2.4.1 Building Technical Regulations (TEK17)

Building technical regulations state technical requirements for buildings within safety, environment, health, and energy to help ensure that the buildings we surround ourselves with are of good enough quality. Under current regulations, TEK17, it is provided in §3-1 that it shall be ensured and documented that all building materials used in a building are suitable for use and contribute to satisfying the requirements in the regulations. This point is central in connection with reuse, as it means that significant properties in the intended use must be able to be documented. It includes, among other things, fire technical and construction technical properties, as well as the content of substances that are harmful to health and the environment (DiBK, 2018).

Furthermore, §9-5 Construction Waste states that "products shall be selected that are suitable for reuse and material recycling". For this to be possible, the accompanying guidance emphasizes that it is necessary that the design contributes to fastening schemes enabling disassembly and that the materials are followed by the necessary documentation which, among other things, indicates fire technical and construction technical properties (DiBK, 2019). The section shall thus ensure that new buildings are made possible for reuse, but no requirement related to that used materials be reused. It is also stated that buildings must be ensured a proper service life and that waste quantities must be minimized.

2.4.2 Legislation for harmful substances to health and the environment

The legislation that controls pollution of the external environment, as well as the content of substances that are hazardous to health and the environment in building materials, is central in connection with reuse. Many building materials contain some substances that are not easily degradable and that can accumulate in nature, at the same time as they can be toxic and have serious long-term effects on both health and nature (Hambra and Hjellnes Consult, 2013; SINTEF Building Research, 2018). In connection with reuse, it is most important to point out that it is not legal to sell or reuse materials with substances that are harmful to health and the environment or where the content exceeds certain maximum values (Asplan Viak, 2018).

Under TEK-17 §9-7 (1), the possible content of substances that are harmful to health and the environment in buildings must be mapped by all measures in existing buildings (Building Technical Regulations, 2017). Furthermore, an environmental remediation description must be prepared that helps to ensure separation and safe handling of other waste. Environmental mapping is required for all projects where a waste plan is required by §9-6 in TEK17, for the following measures:

a) construction, extension, and substructure of a building if the measure exceeds 300 m² BRA (usable area)

b) significant change, including facade change, or significant repair of a building if the measure affects a part of the building that exceeds 100 m² BRA

c) demolition of a building or part of a building that exceeds 100 m² BRA

d) construction, extension, substructure, alteration, or demolition of structures and facilities if the measure generates more than 10 tons of construction and demolition waste

When choosing materials, it is required in TEK17 §9-2 that «Products with or without a low content of substances that are harmful to health or the environment shall be selected». In the guide to the provision, reference is made to the Norwegian priority list and the candidate list for REACH[6] for substances that should be avoided. The two lists overlap somewhat and together have over a hundred substances, in addition to the fact that there are constantly updates with new substances that must be avoided (Hambra and Hjellnes Consult, 2013).

The Product Regulations, or «Regulations on restrictions on the use of chemicals that are hazardous to health and the environment and other products», which are authorized in the Product Control Act (1977), are intended to limit the use of substances that are harmful to health and the environment in products. A reused building product that has been inspected and possibly decontaminated for contaminants and does not come at the expense of the bans in the REACH list, which are substances that give great cause for concern, will meet the requirements of the Product Regulations (Asplan Viak, 2018; Norwegian Environment Agency, n.d.). In the opposite case, it is not legal to use or reuse products where the content of substances that are harmful to health and the environment exceeds the maximum limits.

The substitution obligation, §3 a, in the Product Control Act states that actors who use products containing substances that are hazardous to health and the environment must investigate alternatives that can reduce risk. It is therefore recommended in the provision to choose products with an approved pre-assessment of the content, by the Nordic Ecolabel, ECO-product, or SINTEF Technical Approval (DiBK, 2017).

"Act on protection against pollution and waste" (Pollution Act, 1981), is also central in connection with reuse. The purpose of the law is simplified to ensure safe environmental quality and protect the external environment from pollution. Reduction of waste volumes and improved treatment of waste are key. The Waste Regulations, which are authorized in the Pollution Control Act, deal with, among other things, how the waste is to be treated, including requirements for landfills, incineration, etc. It also defines limit values for when waste becomes hazardous waste, as well as how it is to be stored, transported, and handled. Thus, hazardous waste must be delivered to an approved reception, and cannot be reused (Asplan Viak, 2018).

[6] UK registration, evaluation, authorisation and restriction of chemicals. https://www.hse.gov.uk/reach/

2.4.3 Regulations on documentation of construction products (DOK)

Construction products sold in a market must comply with the Building Products Regulation from the EU, which aims to ensure the free flow of construction products in the European market (SINTEF Building Research, 2016). Regulations on documentation of construction products (DOK) implement in the Building Products Ordinance in Norway and were introduced in January 2014. DOK does not distinguish between used and new building products and sets requirements for the declaration of product properties and benefits and quality assurance of the production phase. The Construction Products Ordinance divides products into five system classes, with different requirements for testing and independent control in the production phase. It has been chosen not to go deeper into the requirements that apply to every individual product group in this thesis, but rather to provide an overall picture of relevant guidelines. Simplified, one can divide into three scenarios for handling according to DOK (SINTEF Building Research, 2016):

1) There is a harmonized product standard for the building product, and CE marking[7] is required before sale.
2) There is no harmonized product standard for the building product, and it is chosen to prepare an ETA (European Technical Assessment) based on an EAD (European Assessment Document). It is then required to CE-mark the product before the sale (Kilvær et al., 2019).
3) The construction product has no harmonized standard. Significant properties and benefits related to load-bearing capacity, fire safety, energy, etc. must, in any case, be documented.

Most building materials are covered by a harmonized product standard, and must thus be CE marked (Asplan Viak, 2018). It is pointed out that the CE mark does not confirm that the product is suitable for use in buildings in Norway, and suitability must always be assessed under TEK (Weber Saint-Gobain, 2019). In scenarios 1 and 2, the product must also be accompanied by a declaration of performance (DoP). Relevant control bodies with the authority to perform technical tests as well as issue certification documents are designated in the NANDO[8] database. These include SINTEF and NEMKO[9] (SINTEF Building Research, 2016).

It is the documentation requirements that were applicable at the first sale of the building product that will also be applicable at the time of sale for reuse. This means that building materials produced and sold before the Building Products Ordinance came into force have different and often simpler documentation requirements than new products. If the necessary documentation from the time of production can be obtained, this will still be valid for new sales if the following conditions are met (Kilvær et al., 2019):

- The properties of the building product are still the same
- The building product is sold under the original product name
- The building product is sold with original documentation

[7] CE marking (CE = Conformité Européenne) is the visible proof that a product is considered to meet the requirements laid down in one or more of the new method directives / regulations.(Standard Norway, 2022)

[8] The database of notified bodies (NANDO). https://ec.europa.eu/growth/tools-databases/nando/

[9] Electrical Product Testing & Certification | Nemko.www.nemko.com

There is uncertainty about how the top point should be taken care of. It is emphasized that the above points are not met if the seller wishes to make changes to the reuse-product, declare new properties, or change the product name on it. As mentioned, DOK occurs when a building product is sold in a market to a third party. The requirements in DOK will therefore not apply if the building product is kept internally in its organization. This provides a good opportunity for large builders to reuse materials, without having to comply with EU regulations (Sørnes et al., 2014).

2.4.4 Exceptions and uncertainties related to the regulations

There are some exceptions to the requirements of the Building Products Ordinance (DOK). This applies to:

1. Materials of high value in public-protected buildings.
2. Building materials that are produced on-site.
3. Building materials that are individually produced.

Kilvær et al. (2019) argue that it is undesirable to have an increased degree of machining on the construction site because, from experience, it leads to less demountable buildings and a lower grave of process control. Lawyers at "Kluge Advokater" also point out that there is a risk associated with relying on the last exception rule. This is because the product must have been produced outside the manufacturer's «normal production», which can be challenging to refer to from a legal perspective and it is uncertain how DiBK practices the rule (Nyland and Apelseth, 2019).

The Building Products Ordinance is based on new products, and it is thus the manufacturer of the product who is responsible for declaring the products' properties, production control, and quality assurance. If further documentation of the properties of a building product is required, the seller of the product will, according to DOK, take on the role of producer (Kilvær et al., 2019). As the regulation is intended to apply to producers with series production and developed production control systems, it is uncertain how this will be taken into account when reusing. There is also uncertainty associated with the necessary documentation if it is not possible to prove at what time the building product was produced, and thus what requirements were applicable at that time. Figure 2.10 presents issues related to DOK in the event of reuse.

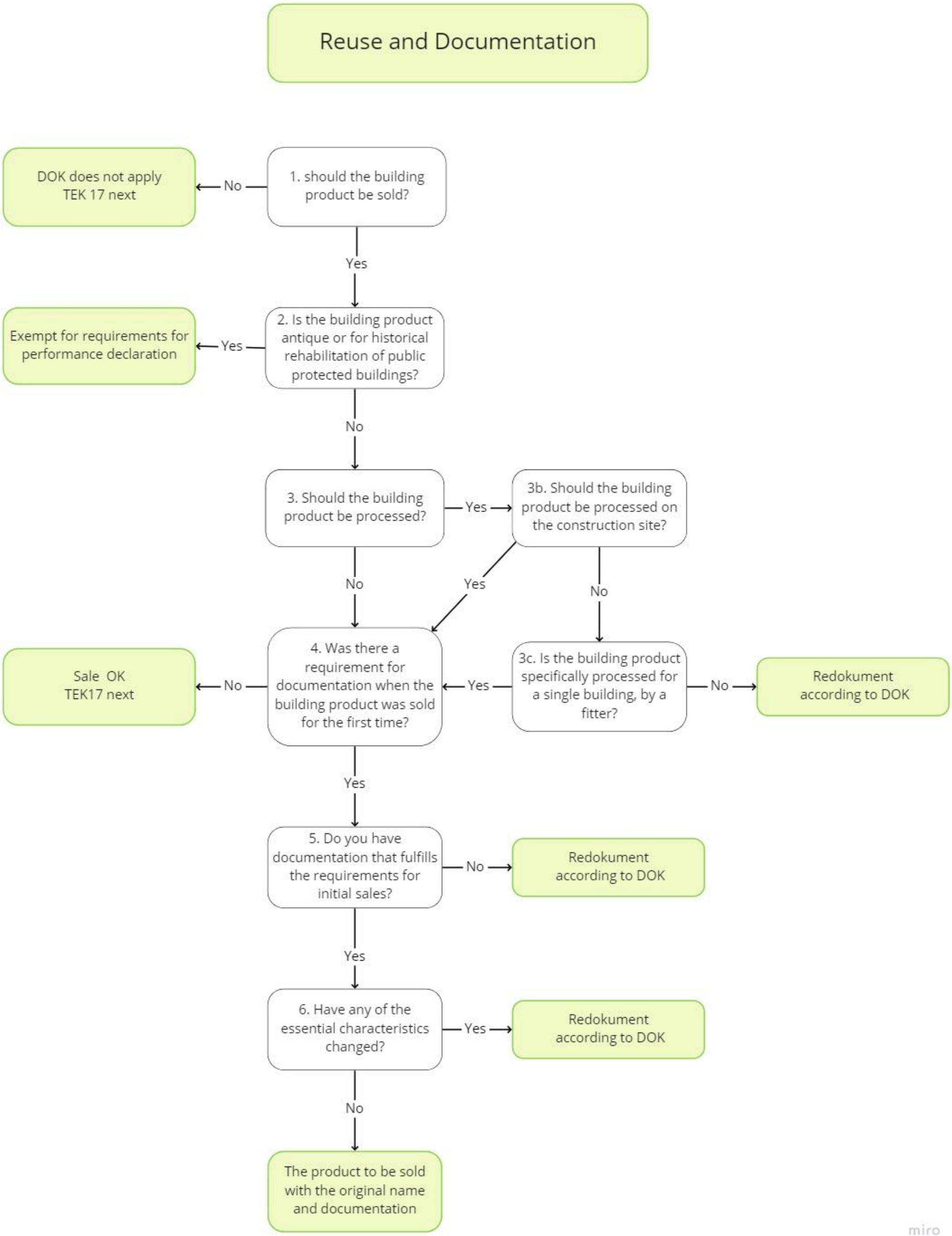


Figure 2.10: Flow chart for documentation and sales by the regulations (Kilvær et al., 2019).

2.5 Today's reuse practice

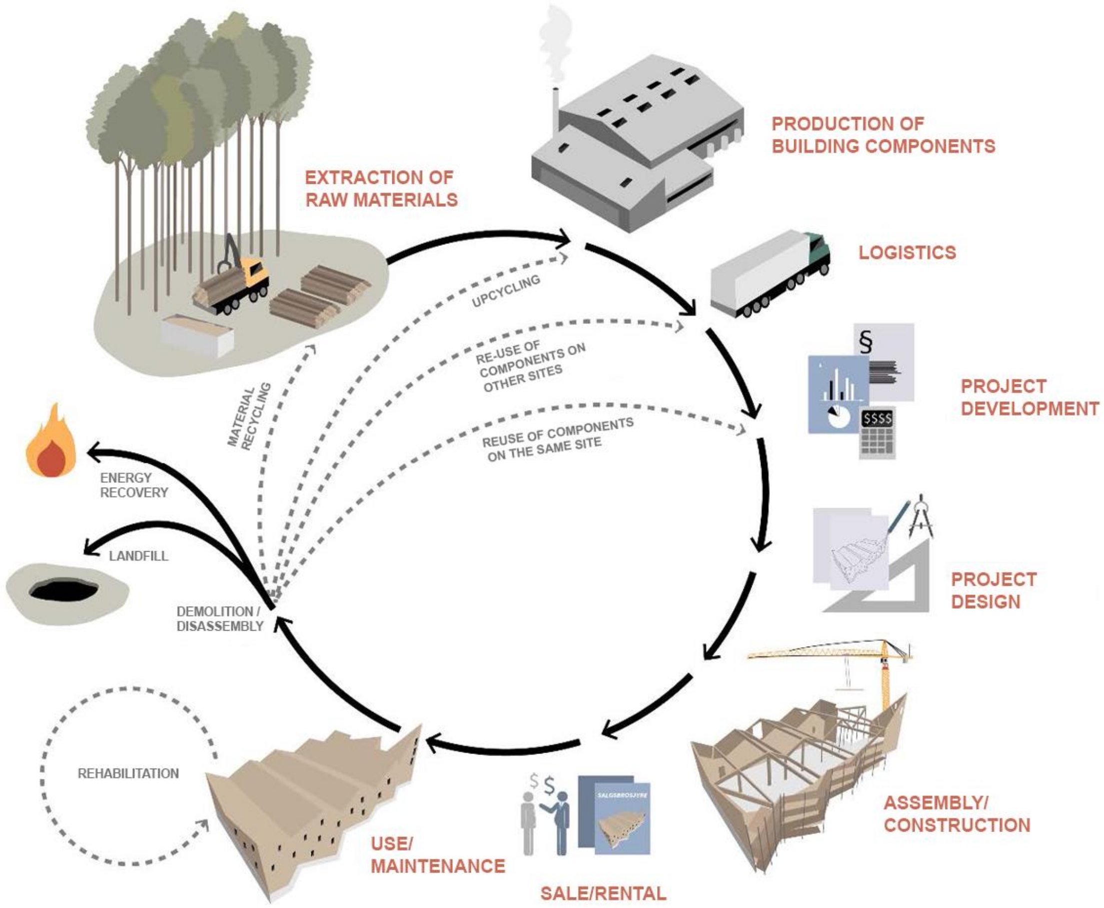


Figure 2.11: Value chain for new produced building components (Asplan Viak, 2020).

The market for reusable materials can be described as poorly set in the system and constantly evolving in terms of the professional part of the construction industry (Asplan Viak, 2018; Sunde et al., 2020). There is an increasing number of players who show interest in reuse, but the degree of reuse is low even though interest is high. "When the will in the industry is there, and it is technically feasible, the lack of reuse and the large production of waste are symptoms of a system that lays behind" (Kilvær et al., 2019, p.118). The scope of reuse in the industry is largely limited to a selection of pilot projects, and there are still many unsolved questions in connection with how the reuse of various building materials can be properly implemented in practice and put into a system (Kilvær et al., 2019; Asplan Viak, 2018; Asplan Viak 2020).

When implementing reuse in construction projects today, many new issues thus arise compared with the use of new construction products, and this can be a complicating factor as the market is today (Asplan Viak, 2018; Kilvær et al., 2019). How Reuse can be carried out will largely vary depending on the type of reuse that is relevant (internal, external, local, and reuse on other sites), what materials are in question, and what function they are to fulfill. This chapter is thus very general but is intended to provide an overall picture of how reuse is practiced today. Figure 2.11 shows the value chain for a typical new material/product, while Figure 2.12 presents the value chain for used building materials and products.

2.5.1 The general Practice

For the implementation of reuse in construction projects, it is first and foremost important that it is desirable from the developer's point of view, as it requires more effort along the way and can lead to the uncertainty associated with the final design of the building and cost development in the project (Rognlien, 2002). According to Rolingen (2002), the examples of questions that are important to ask from the beginning in reuse projects are:

- What is the level of ambition for the project, and what degree of reuse should it be?
- Which reusable materials are built that it is desirable to use?
- What requirements are set for these materials?
- To what extent are extra costs associated with reuse accepted?

2.5.2 Project design/planning

Designing with reused building materials can be time-consuming, and to be able to find good solutions, it is recommended to set aside sufficient time for design in the progress plan (Leland, 2008). It may be necessary to make adjustments to the originally planned design, depending on what materials are available in the right time frame with a view to the progress of the project (Gorgolewski, 2018; Asplan Viak, 2018).

As it is not certain that it is possible to obtain the desired volumes or dimensions of the reusable materials, a flexible way of thinking and goodwill from the design team is required to make adjustments (Gorgolewski and Morretin, 2009; Leland, 2008). It is also beneficial to facilitate an integrated design process with collaboration across disciplines and with the influence of the executive/contractor already in the design phase. This will be able to facilitate finding good solutions at an early stage, where the potential for influence is greatest, while at the same time one must assume that design can go even more parallel to the construction phase itself (Rognlien, 2002; Leland, 2008).

2.5.3 Material acquisition/procurement

Acquiring or obtaining reusable materials can be time-consuming. There is a lack of a well-functioning marketplace where reuse can be safely and legally traded or made available to professional players. This makes it challenging to combine supply and demand for reused prodcts (Myhre, Widenoja and Kilvær, 2018; Sunde et al., 2020). Information about reuse materials, both internally and externally, is also to a small extent available, systematized, and digitalized (Asplan Viak, 2018; Kilvær et al., 2019). Thus, the exchange of materials takes place to a large extent by the requesting project itself finding relevant demolition and conversion projects (an exchange platform) or examining its portfolio for products with reuse potential. Contacts and collaboration with other actors can be central (Nußholz et al., 2019). Concerning the reuse of inventory, Sunde et al. (2020) describe that this has to a small extent been anchored in an overall strategy or objective among municipal actors and that there is a lack of systematics.

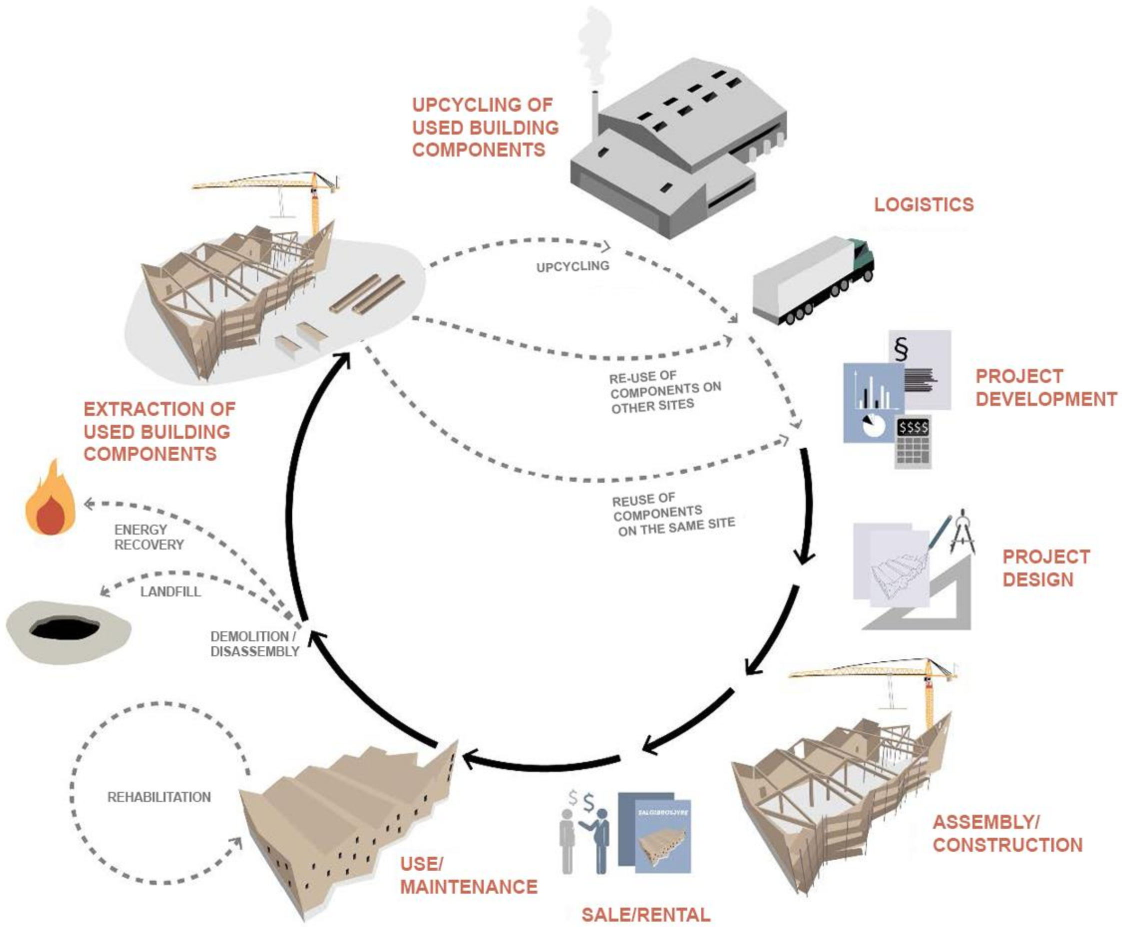


Figure 2.12: Value chain for used building components (Asplan Viak, 2020).

If materials are obtained from other projects, then it will be dependent on the timing of procurement corresponding to the progress of the construction project. This provides low predictability in the quantities of materials that can be obtained. To reduce uncertainty and ensure that the materials are in place at the right time, the materials can be tried to be obtained early in the process. However, this can create an increased need for intermediate storage, which imposes additional costs on the project (Asplan Viak, 2018, 2020; Gorgolewski, 2008).

Several players are working to promote and scale up the reuse market, and want to develop a reuse database that can make visible what is available from reuse materials. Here are some key players highlighted:

- AV Reuse[10]: Asplan Viak developed a system for reuse mapping and design of used building materials. With AV Reuse, the materials found in existing buildings are registered, for later reuse in rehabilitation and new projects. A separate app makes it easy for builders to map available materials. (Asplan Viak Reuse, 2022)

• *Loopfront[11] previously "Greenstock"*. In 2019 the company developed a digital platform adapted for reuse and circular processes. The platform is reserved for

[10] https://www.asplanviak.no/verktoy/ombruk/

[11] https://www.loopfront.com/no

internal reuse with large building owners with several buildings. NTNU, Trondheim municipality, and Asker municipality are examples of their customers. Later in 2021 launched the next generation of the platform, which addresses the entire value chain. From mapping and documentation to collaboration, logistics, and reporting (Loopfront, 2022).

• *Resirqel*[12] is a reuse consultant who offers reuse mapping and material management, and they have sales of reuse products via a digital website and its premises in Oslo. The company also assists with advice for project management and reuse in various phases (Resirqel, u.å.). Recently, in collaboration with "Ragn-Sells Group" (Ragn-Sells, n.d.), they launched the concept «Reuse Bank» for a more efficient collection of surplus materials by placing containers near major construction projects (Resirqel, 2020a). The company has been a specialist and content developer for the guide "Reuse mapping and order- this is how you do it ", published by Green Building Alliance "Grønn Byggallians" and State Construction "Statsbygg" (Green Building Alliance, 2021), and opened in January 2021 "Circular Resource Center" in collaboration with, among others, "Pådriv" and "Statsbygg". This is a warehouse building where used building materials are to be temporarily stored.

• *Rehub*[13] is an online hub that connects supply and demand for the reuse of building materials including necessary additional services, to make it easier to implement reuse in construction projects, especially with a focus on digital opportunities. Rehub wants to combine many services in one unified industry platform (Haugen, 2019).

• *Madaster*[14] is a Dutch concept and platform, which will function as an online library for materials in construction. By giving building materials a material passport, and thus an identity, the idea is that construction can be considered material depots for further use (Madaster, u.å.). There are several who want to use this concept in Norway (Circular Norway, 2019).

Today's demolition practice largely means that materials are destroyed in the process. To enable reuse, the materials must be dismantled gently to secure against possible damage so that the materials can be used further (Asplan Viak, 2018, 2020; Leland 2008). This type of practice is often called selective demolition or disassembly (Addis, 2012). Dismantling is considered a more time-consuming process that may involve increased costs but also allows for a higher degree of sorting of the materials, which entails lower disposal costs (Bohne and Wærner, 2014). For dismantling to be carried out rather than traditional demolition, there must still be sufficient willingness to pay the client, and there must be a demand for the materials (Asplan Viak, 2018).

Before demolition or disassembly measures of a certain size, an environmental mapping description shall be prepared, described in subchapter 2.4.2, in which possible substances that are harmful to health and the environment are detected (SINTEF Building Research, 2011). This work, in combination with a possible reuse mapping, form the basis for which materials should be taken care of for possible reuse.

[12] http://www.resirqel.no/
[13] https://www.rehub.no/
[14] https://madaster.no/

2.5.4 Logistics related to storage and transport

After disassembly from previous use, the reusable materials must be handled during transport and any processing, testing, and intermediate storage. This entails the use of resources in the form of costs, equipment, and labor, and costs will therefore be incurred. The logistics are then handled by the parties involved in the project, and the risk of any damage in the handling must be distributed (Asplan Viak, 2018, 2020; Kilvær et al., 2019).

Necessary conditions that must be taken care of when handling and intermediate storage will vary considerably between different materials. For example, this applies to the need for protection against rain and moisture, as well as the need for space. Materials of large quantities and dimensions will require large areas or premises for intermediate storage, which can drive up costs. Heavier materials will also lead to greater greenhouse gas emissions in transport, and transport stages should be limited to ensure a positive effect on the life cycle analysis (Kilvær et al., 2019). Reuse will, according to Sunde et al. (2020) most cost-effective when the reuse products can find their way directly from one building to another. To get reuse in practice, however, intermediate storage will often be necessary.

The Dutch report "Reuse of HSC" cites two examples regarding the reuse of hollow-core slabs, one of which used a vacant plot near the project for storage and thus got the reuse, while in the other example it was such a confusing logistics process that reuse was not possible (Naber, 2012). Good logistics are therefore important to be able to carry out reuse in practice. For efficient logistics, thoughtful handling of the materials during and after disassembly is generally recommended to facilitate a systematic overview of the various products along the way. It can often involve a form of marking based on type, location, or order (SINTEF Building Research, 2011).

Intermediate storage is generally resource- and area-intensive and the project may depend on finding premises with low rental prices on local plots to keep the costs associated with storage down. This can be challenging in big cities. Intermediate storage is currently an economic and logistical challenge (Kilvær et al., 2019).

2.5.5 Quality assurance and compliance with the legislation

Regardless of whether it is internal or external reuse, the materials must be quality assured and it must be documented that the material is suitable for use if it will affect technical requirements (Asplan Viak, 2018, 2020; Sørnes et al., 2014). Although Building Technical Regulations (TEK) state that "products suitable for reuse and material recycling shall be selected" and the Building Products Ordinance states that "buildings shall be constructed, used and demolished in such a way that buildings and materials and parts of buildings can be reused or recycled after demolition", is the lack of concrete, measurable requirements and follow-up of the extent to which those who demolish and build new today facilitates reuse and reusability a significant barrier to a more circular and resource-efficient construction industry (Asplan Viak, 2020, p.168).

Current legal guidelines, as discussed in chapter 2.4, are therefore described as challenging. There is a lot of uncertainty about how reuse can be carried out properly and following the regulations, which are based on new products and are not adapted to reuse. Resirqel writes: "Uncertainty about regulations, standards, and procedures constitute a problem for reuse on an industrial scale" (Kilvær et al, 2019., p.4). Many actors today work hard to clarify and find solutions for how processes related to quality assurance, testing, certification, and re-documentation for various building materials can be carried out responsibly (Asplan Viak, 2018; Kilvær et al., 2019).

The Building Products Ordinance is especially mentioned as a barrier to the sale of reuse products as it appears today (Lotherington, 2018; DiBK, 2017). Among other things, it is challenging to meet the requirements of the regulations if the original documentation for the products is not possible to obtain. Asplan Viak (2018) claims that the origin of the reusable materials is often unknown and that this means that few will be able to take responsibility if it later turns out that the use of the materials poses some disadvantage to the client. According to the Building Case Regulations (2010) (CASE10) §12-6 (2), there is a requirement that the responsible company must keep documentation for the fulfillment of its liability after the building has been completed, but only for 5 years. Documentation associated with the existing building stock is in addition rarely stored digitally, but rather preferably placed in a binder in archive rooms (Kilvær et al., 2019).

The consequence of a lack of documentation, or that it is no longer valid due to changes in the product's properties, is that the product must be re-documented if it is to be sold in a market (Kilvær et al., 2019). This can be a challenging and time-consuming process, as there is a great lack of accepted and proven procedures. Involved actors must then be willing to take on the risk of increased costs and time use (Kilvær et al., 2019; Asplan Viak, 2018). Corresponding challenges with how key properties for different products can be demonstrated and documented also apply in connection with the fulfillment of requirements in TEK (DiBK, 2018a) This applies to whether the reuse product will have an impact on building technical properties, regardless of whether it is internal or external reuse.

2.6 Requirements for an upscaling of the reuse market and drivers for future development

Previous chapters have highlighted some barriers that players face when implementing reuse. Many possible measures have been proposed in the literature and other studies that could contribute to facilitating increased reuse (Asplan Viak, 2018, 2020; Kilvær et al., 2019; Merrild, Jensen and Sommer, 2016; Moum, Skaar and Midttun, 2017). This chapter will address some aspects that are central to the resale market being scaled up, with proposed measures.

What is meant by an upscale market is not clear. Intuitively, it is about getting an increase in the market, with some market players in a value chain and certain structures around logistics and practice. To a large extent, it can be about bringing more industrialized processes. Moum et al. (2017) describe the industrialization of the construction industry and construction processes. There is no clear definition of what industrialized construction processes entail, but it is argued that the following elements are central:

- Organization: Good flow of processes through the value chain and good logistics
- Scale: Product and production scope of a certain size
- Technology use
- Automated processes
- Variation: A combination of standardization and tailoring

It is not for granted that the reuse market should represent all of these elements, but it indicates that the current reuse market is still far from industrialized.

2.6.1 Clarifications related to compliance with the regulations

Clarifications are needed in connection with how the regulations are to be complied with, both when selling building materials and when demonstrating the necessary properties for new use (Kilvær et al., 2019; Asplan Viak, 2018; Myhre, Widenoja and Kilvær; 2018). Re-documentation, testing, and certification of reuse products are currently complicated to carry out, and at the same time a prerequisite for the reuse market to be able to scale up. If one finds justifiable procedures for documentation of certain building materials, it could form future practice for similar products (Kilvær et al., 2019). Here, ongoing and future pilot projects can do a lot of groundbreaking work that is very important to the industry.

In light of the EU's major investment in the circular economy, it is possible that in the long term adjustments or changes will be made to the regulations for trading that to a greater extent enable circular material handling. According to the Directorate of Building Quality (DiBK), the EU is in the process where they are considering making changes to the Building Products Ordinance (DiBK, 2019). DiBK participates in audit work, but has no formal voting rights as Norway is not a full member of the EU (Lotherington, 2018). Any adjustments in the regulations may, however, take a long time, and Kilvær et al. (2019) emphasize that for the time being the starting point must be the regulations that are in force today.

2.6.2 Improved financial framework conditions

Despite the challenges associated with the financial framework for reuse, It is currently possible to receive financial support for projects and initiatives that want to invest in reuse from actors such as Enova, Innovation Norway, FutureBuilt, and Klimasats (Asplan Viak, 2018; Innovation Norway, 2020; Nordby, 2020; Norwegian Environment Agency, 2020). These are relatively new initiatives. The lack of financial incentives for circular material handling and circular business models can nevertheless be regarded as a barrier to an increased degree of reuse (Nußholz et al., 2019).

Below is a selection of suggestions for financial incentives mentioned in the literature listed:

- Increased fees: fees for waste management and delivery to the landfill can be further increased to motivate waste reduction through reuse (Asplan Viak, 2018).

- Value-added tax(VAT) exemption: exemption from VAT on repairs and sales of second-hand products can make reuse products more profitable because it pays off financially (Asplan Viak, 2018).

- Support schemes: financial support for projects with high environmental ambitions, as mentioned above, can motivate reuse (Asplan Viak, 2018). Other support schemes for local recycling centers in the big cities, storage, and certification, as well as the preparation of digital marketplaces, can also be implemented (Sørnes et al., 2014).

- Deposit scheme: take-back schemes in the form of a mortgage can reward waste reduction and create more opportunities for reuse (Nußholz et al., 2019).

2.6.3 Competence development, collaboration, and new business models

Knowledge and understanding of aspects related to reuse practices is an important basis for players in the industry to be able to implement reuse to a greater extent (Asplan Viak, 2018). Thus, reports and supervisors are central to disseminating knowledge and experiences gained in the industry. Furthermore, the reuse of the syllabus for relevant subject areas at universities and colleges could contribute to increased competence in the future (Asplan Viak, 2018). Wizards and guidance services will also be important in making it easier to choose reuse and other sustainable solutions (RENAS et al., 2019).

Furthermore, an increased degree of selective demolition and dismantling will require the development of guidelines and training, so that demolition actors can contribute to creating cleaner fractions when disposed of and more careful handling of the materials (Høibye and Sand, 2018).

The reuse in Norway could be greatly advanced by more communication and cooperation between interdisciplinary actors in the value chain. Especially manufacturers can have an important role and need to be more involved in reuse processes. Planning for and practical implementation of reuse will benefit from a well-functioning research infrastructure (Knoth et al., 2022). Cooperation between actors is highlighted as a prerequisite for increased reuse and a transition to a more circular economy (Asplan Viak, 2019). A good example of this is "Byggfloken", or "Building group" in English, an innovation project with a collection of 26 actors from construction-related companies. The result of the collaboration led to the design of nine concepts for circular value chains, with reuse as an important part of these (RENAS et al., 2019). The report "Circular Economy" in the Nordic Construction Sector also emphasizes that cross-border cooperation is important for developing new business models that can provide returns (Høibye and Sand, 2018).

Circular economy and reuse open up new business models and innovations when it comes to organizing the market (RENAS et al., 2019; Boye, 2019). Increased producer responsibility is included as a key opportunity (Boye, 2019). This means that the supplier is given responsibility for products throughout the service life and at the end of the service life. It will provide an increased incentive to produce durable products that are suitable for material recycling and reuse, and reduce the content of substances that are hazardous to health and the environment (Boye, 2019). According to Wærner and Tabacuru (2019), this is non-existent in the construction industry. Leasing models and sharing economy will also be able to contribute to innovation in terms of reuse (Moum, Skaar and Midttun, 2017; RENAS et al., 2019)

2.6.4 Used material information availability and increased market predictability

As mentioned earlier, the lack of reuse databases creates challenges in the procurement process for reuse (Asplan Viak, 2018; Kilvær et al., 2019). For the reuse market to be able to scale up, there must be more information about what is available for reuse in the market and internally in one's organization. It is therefore proposed to establish digital marketplaces, as well as digital platforms for gathering information (Asplan Viak, 2018). This could contribute to increased predictability in supply and demand for reuse products. A sufficient volume of different reusable materials is necessary to be able to create this predictability and for the reusable market to be able to function on an industrial scale (Kilvær et al., 2019).

Lack of documentation and information about the buildings and the properties of the materials is, according to Rose and Stegemann (2018), also a major challenge. In particular, "as-built" "documentation is often experienced as incomplete and unreliable when it is available (Rose and Stegemann, 2018). In new projects, the collection and storage of sufficient information about the products used will be very important to better facilitate reuse in the future (Asplan Viak, 2018). Information about the materials' quality, technical properties, guarantees, and instructions for disassembly can be collected in a so-called «material passport» prepared by the manufacturers (Luscuere, 2017). This can follow the product throughout its life cycle and be updated during maintenance and other interventions, as well as include specific MOM[15] documentation (Sørnes et al., 2014). Legislation of such a scheme can create a good information base and simplify the process (BAMB, 2019b).

Digital tools, such as BIM models (Building information modeling), can serve as a MOM basis and also contain sufficient information about building materials for reuse purposes if they contain information about how the building is built *"as-built documentation"* (Bjørheim, 2018; Sunde et al., 2020). This is often called a "digital twin". BIM models are increasingly used today for new buildings, but it is also entirely possible to prepare for existing buildings (Sunde et al., 2020). Technology such as laser scanning for BIM will be able to contribute to the establishment of digital models of existing buildings (Fuglesang, 2017; Cobuilder, 2018; Rodahl, 2019). The preparation of digital twins in new projects, which contain "as-built" documentation, is also a key tool (Bjørheim, 2018).

2.6.5 Stricter requirements for sustainable material use

As emphasized earlier, TEK17 sets requirements for the selection of materials that are suitable for reuse and material recycling. How it should be made visible, however, has not been clarified. Setting stricter requirements for circular material procurement and reuse, among other things in the regulations, will mean that the industry must be able to deliver the solutions (Kylili and Fokaides, 2017; Høibye and Sand, 2018). It will be an important incentive to change practice. Sunde et al. (2019) also emphasize the ordering power of builders. They describe the current situation as a classic "hen and egg" situation, where there are few suppliers of reusable materials and in principle, no one demands it either. If demand is secured, they believe that contractors and material suppliers will adapt. Difi's guide to circular procurement will, among other things, help to simplify the possibilities of setting requirements related to reuse (Difi, 2019). Furthermore, the following examples of measures are suggested in the literature:

- Extending the requirement for environmental mapping for hazardous waste to include mapping of reuse potential for the materials before rehabilitation or demolition (Asplan Viak, 2018; BAMB, 2019).

- Inspired by the scheme for the electricity return scheme and other product categories, it can be a measure that the manufacturers introduce a system for take-back at the end of the function or a specific reuse volume for the company (Asplan Viak, 2018). This can be legislated by the authorities, so that the manufacturers can benefit from getting the materials returned, as well as increased insight into how they have worked through use times.

Municipalities can also play an important role in increasing reuse, by setting requirements for builders and setting premises for construction case processing (Asplan Viak, 2018; Sørnes et al., 2014). This can be done by setting requirements for information about reusable materials through the waste plan that is delivered to the municipality. If this plan is submitted earlier, in connection with an application for commissioning, the information can be published digitally and marketed for disposal or sale, thus creating a greater time window to obtain elements and connect to ongoing projects (Asplan Viak, 2018; Sunde et al., 2020).

[15] MOM documentation stand for management, operation, and maintenance.

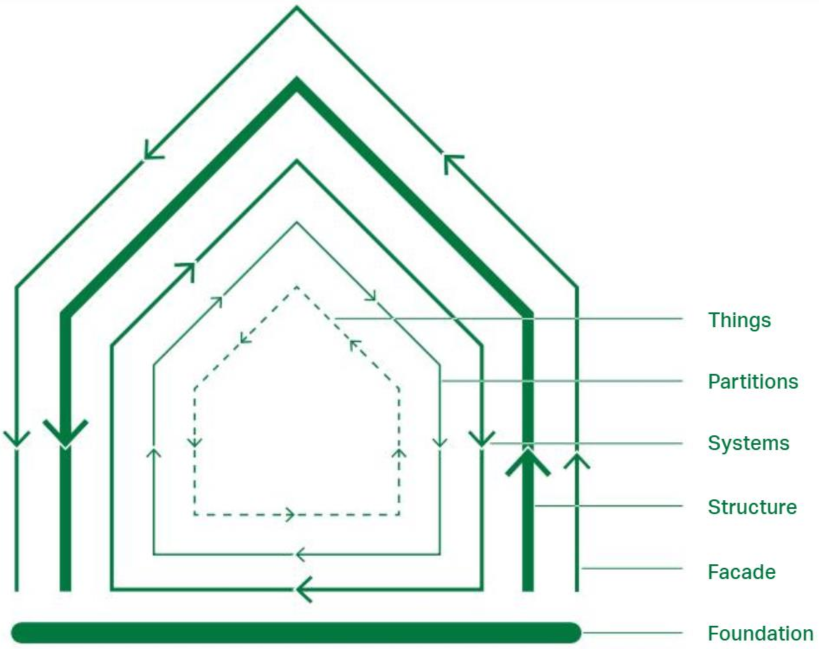


Figure 2.13: Diagram shows the division of elements involved in building with a lifetime (Jensen et al., 2019).

2.6.6 Design of buildings that enable reuse in the future

Large parts of the existing buildings have not been planned so that it will be possible to change function without major alterations or that it will be possible to dismantling the buildings (Leland, 2008; Wærner, 2020). By adapting the buildings to a greater extent with thoughtful material choices and a design that can potentially simplify functional change and dismantling, they may be easier to reuse in the future (Melton, 2020).

<u>The extended service life of buildings and materials</u>

From a sustainability perspective, it is important to ensure a long service life for buildings and building components (Bygg21, 2018a). Lifetime considerations are thus central in the assessment of what is appropriate handling of materials (Bjørberg, Kampesæter, and Listerud, 2009). One can distinguish between functional, technical, aesthetic, and economic service life, and which service life will be limited depending on the situation. Many factors affect the longevity of building components; maintenance, use load and exposure environment, material quality, design and execution. If, for example, the necessary maintenance is not carried out, the service life of many materials will be shorter than expected (Bjørberg, Kampesæter and Listerud, 2009).

Furthermore, it is also important to assess environmentally safe service life, which means that service life justifies the environmental impact that has been reduced when obtaining the material (Nordby, 2009; Sørnes et al., 2014). It is often the case that functional service life occurs before technical service life is reached (Bjørberg, Kampesæter and Listerud, 2009). It will then be necessary to replace the material or product, even if the object could technically still be usable in another function or location. This often leads to materials being considered waste earlier than necessary, which is not justifiable from an environmental perspective.

All buildings consist of many different components with different service lives. Figure 2.13 shows a layering of the components of a building, where the layers have a shorter calculated service life, the thinner the lines. Such a subdivision was made by Brand (1997) and the idea is that it should be possible to change and replace building parts with shorter service life, regardless of the consequences for other parts with longer service life. The parts that are difficult to reach must be durable for a long time, such as foundations and load-bearing systems (Akanbi et al., 2018; Bjørberg, Kampesæter and Listerud, 2009). Fixtures and fittings are often replaced several times during the life of a building, and it should be possible to change without major interventions. The same applies to the building's facade, which is very exposed to the weather (Jensen et al., 2019). In Table 2.3, the estimated lifetimes for the various building parts in connection with the layering are presented.

Table 2.3: Overview of estimated lifetimes for different building parts (Jensen et al., 2019).

Building element	Estimated lifetime	Reuse potential
Groundworks & Foundation	100+ years	The foundation is buried in the ground and is difficult to access, which is acceptable because the element has a long life that can endure several buildings
Load-bearing structure	50+ years	The structure is the spine of the building, so it is acceptable that connections are the least accessible. The lifetime of this element is longer than most buildings so it is important it can be taken out and reused in another building.
Fasade	30+ years	Due to the facade cladding's exposure to the weather, it is expected that during the building life the facade will be either changed or at least undergo a major renovation, so it is key that these actions can easily be made.
Partitions and systems	10+ years	A building must be able to adapt to the changing needs of its occupants, and flexibility in the partition walls and the technical system is the keystone to achieving this.
Things (items and fixtures)	1+ years	The things we put inside our buildings, furniture, decorations, etc. have in general a very short lifecycle. These things should be thought about regarding the overall use of the building so they did not interfere with the flexibility and reuse of resources.

Increased adaptability, elasticity, and flexibility

The adaptability of buildings is considered, according to Melton (2020), as an important tool to make it easier to use materials and products again in a new location, and thus limit the extraction of new resources then. The term is considered a collective term for generality, elasticity, and flexibility. Generality is about the possibility of changing the building's function without major structural interventions. Elasticity indicates the possibility of changing the size of the building, and flexibility is based on whether the interior room division can be changed within the main framework (Multiconsult and the Building Environment, 2008; Arge and Landstad, 2002). These factors have a significant impact on the ability to reuse building materials and provide incentives to ensure a long life for components, as well as buildings as a whole (Multiconsult and the Building Environment, 2008; SINTEF Building Research, 2004a).

Practical examples of adaptability in buildings are to ensure long spans to enable free surfaces and light interior walls. For many buildings, adding spacious floor heights for adaptability concerning ceiling heights and technical infrastructure, as well as technical mezzanines will be a good measure (SINTEF Building Research, 2004a; Multiconsult and the Building Environment, 2008).

Design for disassembly and reuse

The concept of design for disassembly and reuse (DfD) is based on materials and solutions being designed so that it is possible to take them apart (Leland, 2008). The aim is to ensure that materials can be included in a circular cycle and adapted to new use, relatively either through reuse or material recycling (Jensen et al., 2019). The design of the buildings and the location of materials, therefore, have a close connection with the building element divisions presented earlier in Figure 2.13.

To enable the disassembly of materials and products, the use of fastening mechanisms and connections will play a key role. For example, it is recommended to use screws instead of nails, lime mortar instead of portland cement, and soluble fasteners instead of glue (Jensen et al., 2019). According to Nordby (2009), it is also important to limit the choice of materials, ensure high generality, and have available information about the materials. Modular design with standardized sizes is a good tool for ensuring high flexibility in the buildings (Minunno et al., 2020). Finally, it is important to choose materials with no or little content of substances that are hazardous to health and the environment to enable future reuse (Nordby, 2017). If toxic substances cannot be avoided in the materials, it is recommended that they can be easily identified and dismantled (Leland, 2008).

Circular buildings

In connection with the implementation of the circular economy in the construction industry, circular buildings have gained significant importance. There are many different definitions of the term, but Circle Economy (CE) defines a circular building as a building that has been developed, used, and reused without unnecessary resource consumption or environmental impact (Circular Economy et al., 2018). FutureBuilt has prepared a more specific definition for circular buildings, a specific definition*: "A circular building facilitates resource utilization at the highest possible level, and consists of at least 50 percent reused and reusable materials and components"* (Nordby,2020).

On their criteria set for circular building, they divide the concept further into five themes, which are; (1) environmental-based decision on rehabilitation or demolition, (2) resource utilization in demolition work, (3) reuse of materials, (4) reusability, and (5) Adaptability (ability to change). The FutureBuilt criteria for circular buildings v.02 are illustrated in figure 2.14. The elements mentioned above, such as extended service life, increased adaptability, and design for disassembly, therefore play an important role in the design of circular buildings. As mentioned before this research report will be focusing only on (3) the reuse of building materials (Nordby,2020).

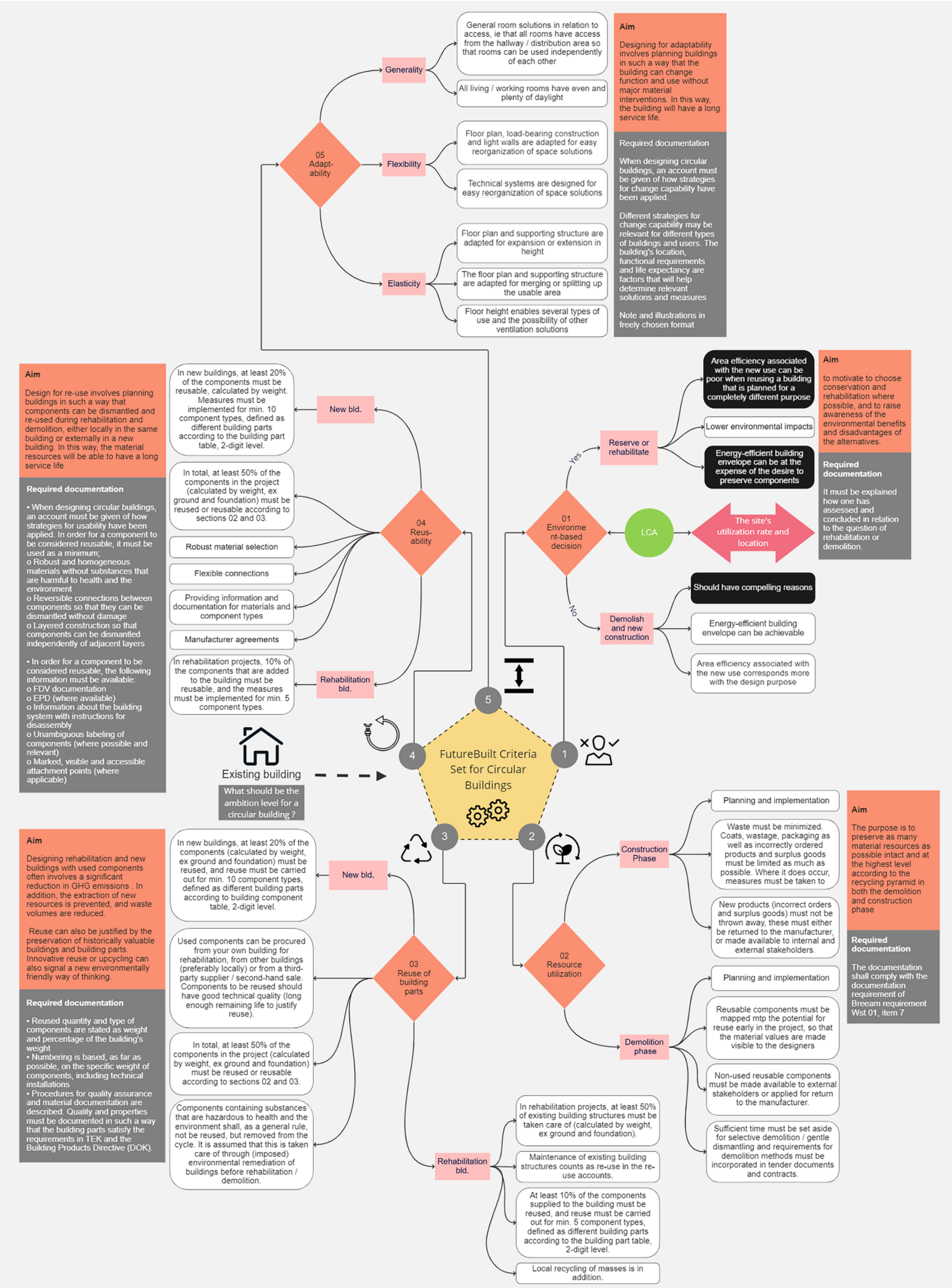


Figure 2.14: FutureBuilt Criteria for circular buildings

Self-produced based on (Nordby, 2020)

2.7 Reuse as sustainability assessment method-FututreBuilt circular building criteria v.02 against BREEAM NOR v.06

2.7.1 Rehabilitation scope in BREEAM-NOR v6.0

What is BREEAM

BREEAM is the world's leading science-based suite of validation and certification systems for a sustainable built environment since 1990 (BREEAM, n. d.). BREEAM is an abbreviation for "Building Research Establishment's Environmental Assessment Method". In Norway, there is a customized BREEAM manual to ensure relevance and applicability "BREEAM-NOR". BREEAM is owned by British Building Research Establishment (BRE), which can be compared to SINTEF in Norway as a testing and research center.

The scope of BREEAM-NOR for new buildings is primarily quantification and reduction of environmental impacts from new building projects. The version 6.0 manual is therefore not intended for the assessment of rehabilitation projects. Until a separate certification method is developed in Norway for the rehabilitation of buildings, however, builders can under certain conditions use BREEAM-NOR v.06 to certify rehabilitation projects (Green building alliance, 2022).

Definition of new buildings and extensions

New buildings and extensions can use the BREEAM-NOR manual without adaptations, see alternative A in figure 2.15. As a general rule, a new building is defined as a building that is built from scratch and generally does not incorporate or include any parts of an existing building (Building Technical Regulations, 2016). Where a building is erected on the site of an existing building, it will be defined as a new building as long as no part of the previous building above ground level is included. Basement, lower floor, or ground floor can be included. Extensions can also share certain building parts with an existing building, such as a wall in an infill project.

Total rehabilitation

Total rehabilitation projects can use the BREEAM-NOR manual without adaptations, see description of alternative A below. In BREEAM-NOR, the term rehabilitation is used throughout, but a distinction is made between total rehabilitation and other rehabilitation projects. Total rehabilitation is the same as the main renovation, a term that is used in the Planning and Building Act's descriptions of work on existing buildings (Kynbråten and Larsstuen, 2015). Total rehabilitation means radical changes or repairs that are so extensive that the entire structure is essentially renewed.

It should be noted that the vast majority of total rehabilitation projects will reuse most of the building's existing load-bearing systems. In some cases, the facade is retained, although it can be repaired or rehabilitated.

Building parts that can be continued in a total rehabilitation project:

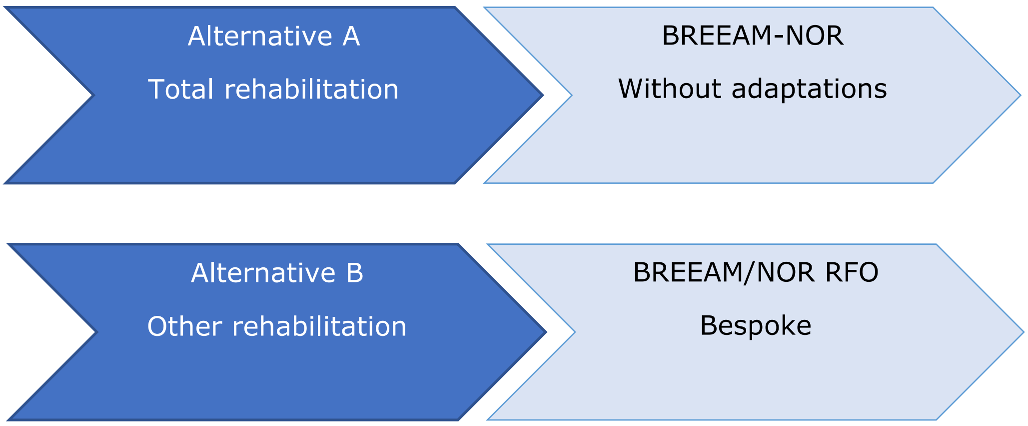
- Load-bearing structures
- Basement, underground floor, flooring/covering against the ground, or other building parts below ground level

Other rehabilitation

Projects that do not meet the requirements described for "Total Rehabilitation" can use the BREEAM-NOR manual with adaptations/adjustments. See the description of alternative B below.

Available Alternatives

There are two alternatives available for rehabilitation depending on the scope. See figure 2.13 and the description below.



Alternative A

In Alternative A, the project can use the BREEAM-NOR manual without adaptations. This means that the scope of rehabilitation must correspond to BREEAM-NOR's definition of total rehabilitation (see above).

Buildings that have protection regulations associated with the building must always choose alternative B.

Some projects may be suitable for alternative A even if the scope of rehabilitation does not correspond to BREEAM-NOR's definition of total rehabilitation. The auditor can then make a technical clarification to the Green Building Alliance on behalf of the project.

Alternative B

For all rehabilitation purposes other than alternative A, the project must have a BREEAM-NOR Bespoke RFO criteria set prepared. The criteria set is an adaptation based on the BREEAM-NOR manual but includes elements from BREEAM International Refurbishment & Fit-Out. This is to adapt the criteria and points opportunities better to the project. The principles that form the basis for the preparation of the Bespoke criteria set and the Bespoke process itself is like other Bespoke projects

Figure 2.15: The alternatives A and B for rehabilitation projects (Green Building Alliance, 2022)

Scope of rehabilitation in RFO Bespoke

BREEAM-NOR RFO Bespoke is divided into four parts, see table 2.4. The scope of the project may include one or more parts.

Table 2.4: Scope of rehabilitation and available parts (Green Building Alliance, 2022)

Part	Element	Component	Description
Part 1	Envelope	1. External walls 2. Roof 3. Windows	Applies when the rehabilitation covers more than 50% of the building element's surface or 25% of the surface of the building's envelope in total. Two or more of the building elements in the list must be included in the scope.
Part 2	Main installations	1. Ventilation 2. Heating 3. Cooling 4. Sanitary facilities 5. SD system 6. Energy supply	Two or more of the main installations on the list need to be replaced or upgraded
Part 3	Local installations*	1. light 2. control systems 3. local ventilation 4. local heating 5. local cooling 6. local water heater	One or more local installations from the list must be replaced or upgraded. Light must as a minimum be included due to minimum requirements in the issue Hea 01.
Part 4	Interior	1. Surface treatment wall 2. Floor covering 3. Ceiling and roof systems 4. Partitions 5. Technical floor 6. Furniture and fixtures (fixed) And at least one of the following: 1. Sanitary equipment 2. Other equipment (fixed) 3. Local electrical installations, e.g. sub-meters	Two or more items in the list need to be replaced or upgraded. Surfaces must be included in the assessment if you want to achieve a higher classification level than Good. The rehabilitation must cover at least 50% of the area of the building component.

* Local installations are defined as installations that supply a specific area and that can be connected to central installations within the rental area.

For the available classification levels for the various parts, the classification level that can be achieved for alternative B depends on which, and how many parts from table 2.4 are included in the scope of rehabilitation and possibly the combination of these. Due to the minimum requirements for the various classification levels in BREEAM-NOR, it is difficult to achieve a higher classification level than "Very Good" if the scope only includes one or two of the four parts (Green Building Alliance, 2022).

Combined new construction-Rehabilitation projects

If the project consists of a combination of new construction and rehabilitation, either alternative A or B can be chosen.

The options are described below:

1. The project uses alternative A for the entire project, ie both for the new building and the rehabilitation project.
2. The project uses alternative A for the new building. The rehabilitation project is omitted from the scope of certification
3. The project is divided into two. The new building uses alternative A. For the rehabilitation project, a BREEAM-NOR RFO Bespoke criteria set is prepared according to alternative B. The project receives two certificates, one for the new building part and one for the rehabilitation part.
4. If the project is mainly a rehabilitation, but with some new components, alternative B can be used for both the new building part and the rehabilitation part if the requirements described in Table 2.5 below are met. This means that the project receives one certificate for the entire project.

Table 2.5: Relationship between the existing building and new building/extension using option 4. (Green Building Alliance, 2022)

	Division 1	Division 2	Division 3
Existing Building	< 500 m²	> 500 og < 2500 m²	> 2500 m²
New Building/Extension	<40% of the area of the existing building	<30% of the area of the existing building	<20% of the area of the existing building

Both of the case projects are rehabilitation projects with extensions (combined new construction-rehabilitation) and therefore will be considered under alternative B, option 4. Division 3 for both of the existing buildings (3350 m², 8720 m²) for KA13 and KA23 respectively. For the extensions, division 2 (20.9%) for KA13 and division 3 (2.5%) for KA23. See table 2.6 below.

Table 2.6: Relationship between the existing building and new building/extension using option 4 in case study projects.

	Division 1	Division 2	Division 3
Existing Building	-	-	KA13, KA23
New building/Extension		KA13	KA23

2.7.2 Reuse scope in BREEAM-NOR v6.0

BREEAM-NOR v6.0 has several important changes, among others, the reuse of building materials and products (Green Building Alliance, 2022a). In BREEAM-NOR manual v6.0 and under «Criteria» are included the issues that are assessed divided into ten sustainability categories displayed in Table 2.7 as follows:

Table 2.7: Categories and issues in BREEAM-NOR for new buildings v6.0

Categories and Issues in BREEAM-NOR v6.0	
Management	**Health and wellbeing**
Man 01 Concept development and project optimization Man 02 Life cycle costs and lifetime planning Man 03 Responsible for building practices Man 04 Commissioning and handover Man 05 Test operation and follow-up	Hea 01 Visual comfort Hea 02 Indoor air quality Hea 03 Thermal environment Hea 05 Sound ratio Hea 06 Safe and healthy environment Hea 08 Private area
Energi	**Transport**
Ene 01 Building energy performance Ene 02 Energy measurement Ene 03 Outdoor lighting Ene 05 Energy efficient refrigeration and freezing rooms Ene 06 Energy efficient transport systems Ene 07 Energy efficient laboratory systems Ene 08 Energy-efficient equipment	Tra 01 Transport mapping and mobility plan Tra 02 transport measures
Water	**Materials**
Wat 01 Water consumption Wat 02 Water measurement Wat 03 Detection and prevention of water leaks Wat 04 Water-saving equipment	Mat 01 Sustainable material selection – LCA and greenhouse gas calculations Mat 02 Sustainable material selection – product requirements Mat 03 Responsible procurement of materials Mat 05 Robust and climate-adapted construction Mat 06 Material efficiency and reuse Mat 07 Adaptability and reusability
Waste	**Land use and ecology**
Wst 01 Resource management on construction site Wst 03 Waste in the operating phase Wst 04 User involvement in internal surfaces	LE 01 Plot selection LE 02 Ecological risk and opportunities LE 03 Management of impact on ecology LE 04 Ecological change and improvement LE 05 Long-term ecological management and maintenance LE 06 Adaptation to climate LE 07 Floods and storm surges LE 08 stormwater management
Pollution	**Innovation**

Pol 01 Influence of refrigerants Pol 02 Local air quality Pol 04 Reduction of light pollution Pol 05 Noise cancellation	New technology, process, or practice

Each issue defines a performance level (criteria), and the assessed building must meet the criteria for this level (using relevant documentation) to achieve the number of points available for the level. The client or the design team can choose which courses are to be included to achieve the desired number of points and thus the desired classification. However, several topics have minimum requirements. They show what must at least be met to obtain a certain classification (Green Building Alliance, 2022).

The reuse in the BREEAM-NOR scope is covered in three categories; the management, the materials, and the waste out of 9, see figure 2.16 and under the following issues:

- Man 01 Concept development and project optimization
- Wst 01 Resource management on construction site
- Mat 01 Sustainable material selection – LCA and greenhouse gas calculations
- Mat 03 Responsible procurement of materials
- Mat 06 Material efficiency and reuse
- Mat 07 Adaptability and reusability

Mat 01 and Man 01 are relevant to greenhouse gas emission reduction from material use, while Mat 03, Mat 06, Mat 07, and Wst 01 are relevant for the reuse of building materials and products. The above issues together with their goals and criteria set are illustrated in figure 2.17.

Figure 2.16: The BREEAM-NOR sustainable categories (Green Building Alliance, 2022)

Greenhouse gas emission

- Materials (Mat): Materials are one of the largest contributors to greenhouse gas emissions in the Norwegian industry. The new BREEAM-NOR v.06, set, among other important changes, a requirement for greenhouse gas accounts for the building as a whole to have a certificate issued (Green Building Alliance, 2022a). In addition, points for reduction of greenhouse gas emissions are calculated based on NS 3720:

2018 method for greenhouse gas calculations for buildings (Standard Norway, 2018). Reference values are agreed with the Directorate for Administration and Financial Management (DFØ) 's greenhouse gas tool and adapted to different building types (DFØ, 2021). See Table 2.8 below:

Table 2.8: BREEAM-NOR v6.0 rating for reduction of GHG emission

Reduction of greenhouse gas emissions %	Point	Minimum requirement
20%	1	Very Good
30%	2	Excellent
40%	3	Outstanding
60%	Innovation point	

- Energy (Ene): Climate-friendly energy source is rewarded. The same goes for greenhouse gas accounts for energy use.
- Transport (Tra): Here, greenhouse gas accounts are rewarded for transport to and from the building during the building's operating period.
- Construction site (Man): Greenhouse gas emissions on construction sites are measured and reduced. Energy consumption, transport of masses, and waste. Innovation points: A maximum of 10% of the emissions are direct emissions of greenhouse gases on the construction site.
- Management (Man), the project is rewarded for setting up a greenhouse gas budget in the early phase and using it as a basis for setting framework conditions and environmental goals in the project. After completion, the final greenhouse gas accounts for the entire building will be presented and evaluated against terms and goals. This also meets the requirements of the taxonomy and is a minimum requirement from Excellent (Green Building Alliance, 2022a).

<u>Waste and reuse</u>

The goal is to make the projects reduce the amount of waste by designing for less waste (reuse, recycle, prefabricated materials, reduce the number of changes, etc.). The new BREEAM-NOR manual v6.0 rewards the projects that not only sort but also recycle, those that get to reuse, and those who manage to minimize the amount of waste.

- Waste quantities (Wst): BREEAM-NOR rewards projects that have low waste volumes per m².

Table 2.9: BREEAM-NOR v6.0 rating after generated construction waste quantities

Point	Amount of construction waste generated in kg/m² (BRA)	Minimum requirements
1	≤ 40	Outstanding
2	≤ 25	
Innovation point	≤ 19	

- Source Sorting and Material Recovery (Wst): BREEAM-NOR continues to reward source sorting but to a lesser extent. 75% is the minimum requirement from Pass. To achieve the Excellent certification level, the project must also have prepared 70% of the waste for reuse or material recycling. You do not get points here for waste that is delivered to waste incineration. Prepared is meant that it must be sorted and stored so that material can be recycled. This is because as of today it can be difficult to get reception for certain types of waste for material recycling depending on the capacity of the reception and where in the country the project is located.

Table 2.10: BREEAM-NOR v6.0 rating after waste prepared for reuse or recycling

Point	Share sorted	Percentage prepared for reuse or material recycling	Minimum requirements
Minimum requirements No points	75%	-	Pass
1	85%	50%	-
2	90%	70%	Excellent

<u>Reuse</u>

Here are several new topics under the category Materials. In the new Mat 06 - material efficiency and reuse, and reuse mapping is the minimum requirement if there are existing structures on the site. From Excellent, the minimum requirement has been extended to at least 10 of the recommendations in the reuse mapping, and for at least 5 product groups, 20% of potentially reusable building components must be used. A new topic is also Mat 07– Adaptability and reusability, which gives up to 3 points (Green Building Alliance, 2022a). An overview of the reuse scope in the BREEAM-NOR v6.0 sustainable categories is presented in Figure 2.17. Every category is followed by the Goal, relevant issues and assessment criteria.

BREEAM-NOR v6.0 has, among other things, a goal to promote circularity and increase the scope for reuse and availability of reused materials and products, as well as create a market for reusable components (Green Building Alliance, 2022a), see Figure 2.18.

- For the demolition phase, at least 10 measures should be followed, through material mapping, of how resource utilization in the demolition phase is planned and implemented, and at least 5 components should be reused out of the building component schedule.
- For the new building components at least two reused components should be used externally from other donor buildings or preferably surrounding buildings under the demolition for example façade plates and hollow/core slabs.
- In addition, BREEAM-NOR rewards buildings that are planned to be built in the future. These types of buildings are with a clear resource overview or have a material bank circular approach. Furthermore, for those who design for disassembly buildings (DfD) with reusable components in the future such as; load-bearing systems, envelopes, internal components and technical installations.

Management

Man 01 Concept development and project optimization

Goal: The project management shall design and implement sustainability goals, with associated measures and division of responsibilities, for the entire project process.

Assessment criteria:

1 - Planning of design and execution (1 point)
2 - Total greenhouse gas accounts for the life of the building (1 point)
3 - Involvement of external stakeholders (1 point)
4 - BREEAM-NOR AP (steps 2 and 3) (1 point)
5 - BREEAM-NOR AP (step 4) (1 point)

Waste

Wst 01 Resource management on construction site

Goal: To reduce the amount of construction waste by designing and facilitating reuse, recycling and best practice management of resources and waste on the construction site.

Assessment criteria:

1 - Resource management plan (1 point)
2 - Waste quantities (up to 2 points)
3 - Waste sorting, reuse and material recycling (up to 2 points)
4 - Exemplary level: Very low waste volumes (1 point)

Materials

Mat 01 Sustainable material choices - LCA and GHG calculations

Goal: Recognize and encourage the use of building materials with a low environmental and climate impact throughout the construction life cycle.

Assessment criteria

- Prerequisites: early phase greenhouse gas calculation (no points)
- Reduction of greenhouse gas emissions (up to 3 points)
- Exemplary level: 60% reduction of greenhouse gas emissions (1 point)
- Life cycle assessments of the building (LCA) (up to 2 points)

Mat 03 Responsible procurement of materials

Goal: Promote the choice of materials with lower negative environmental, economic and social impacts throughout the supply chain, including extraction, processing and production.

Assessment criteria

1 - Minimum requirements: legally cut and sustainable wood (no points)
2 - Facilitate sustainable procurement (1 point)
3 - Responsible procurement of relevant materials (up to 2

Mat 06 Material efficiency and reuse

Goal: Promote reuse and optimize the use of new materials

Assessment criteria

1 - Reuse mapping and reuse of existing structures (1 point)
2 - Material efficiency (1 point)
3 - Reuse of external building components (1 point)
4 - Exemplary level: FutureBuilt criteria under 2.3 Reuse of building components for circular buildings (1 point)

Mat 07 Adaptability and Reusability

Goal: Avoid unnecessary material use, costs and possible downtime in future conversions, as well as facilitate the reuse of building components and material recycling when the building is to be rehabilitated, dismantled or demolished.

Assessment criteria

1 - Resource overview (1 point)
2 - Ability to change and reusability: recommendations (1 point)
3 - Ability to change and reusability: implementation (1 point)

Figure 2.17: The reuse scope in the BREEAM-NOR v6.0 sustainable categories (Green Building Alliance, 2022)

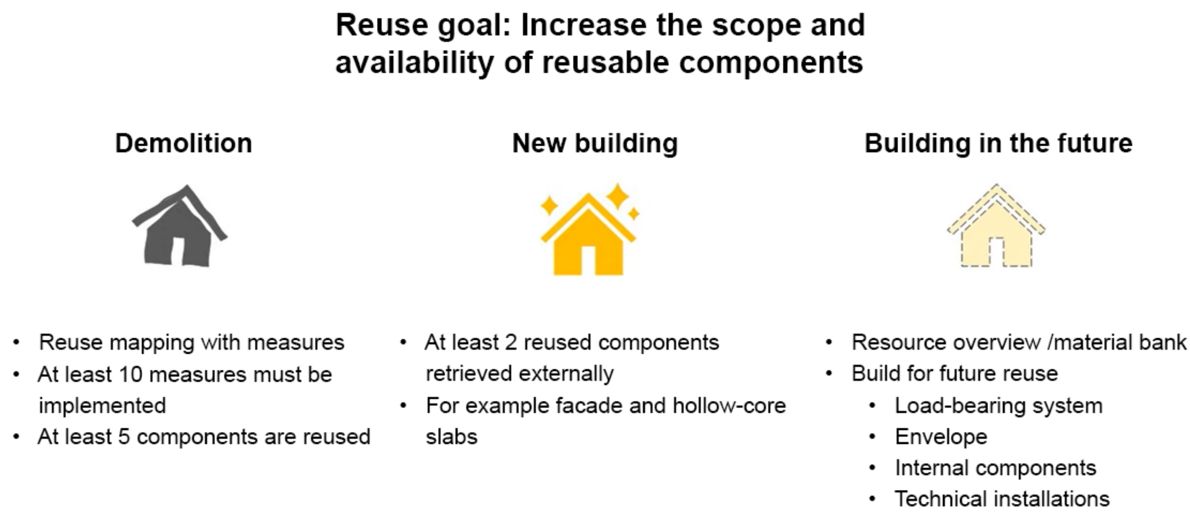


Figure 2.18: The BREEAM-NOR v6.0 reuse assessment (Green Building Alliance, 2022a)

2.7.3 Reuse in FutureBuilt circular building criteria

The FutureBuilt circular building criteria, presented in chapter 2.6.6, have the purpose to motivate reuse and circular principles in rehabilitation, demolition, and new construction and set a standard for what should be the level of ambition for a circular building (Nordby,2020). Its concept covers five issues, see figure 2.14:

(1) 2.1 Environmental-based decision on rehabilitation or demolition
(2) 2.2 Resource utilization in demolition work
(3) 2.3 Reuse of materials
(4) 2.4 Reusability
(5) 2.5 Adaptability (ability to change)

Points 2, 3, 4, and 5 must be answered for all projects. Point 1 must also be answered where there are existing buildings on the site as in our case study buildings. The relevant criteria under each issue are described as follows:

<u>Environmental-based decision on rehabilitation or demolition</u>

- Where there are existing buildings on the site, a thorough assessment shall be carried out to determine what is the environmentally best alternative concerning the question of continued maintenance and repair, degree of rehabilitation, or demolition.
- The assessment must be carried out by an interdisciplinary team of advisers and also executives so that all the advantages and disadvantages of the alternatives emerge.

<u>Resource utilization in demolition work</u>

Demolition phase

- An account shall be given of how resource utilization in the demolition phase is planned and implemented.
- Reusable components must be mapped taking into account the potential for reuse early in the project so that the material values are made visible to the designers.
- Reusable components that are not used in the project must be made available to external stakeholders or sought to be returned to the manufacturer.
- Sufficient time must be set aside for selective demolition / gentle dismantling and requirements for demolition methods must be incorporated in tender documents and

contracts. Dismantling and securing of components for reuse are specified in the demolition description, and requirements are set for understanding the task and references when awarding a contract.

Construction phase

- An account shall be given of how resource utilization in the construction phase is planned and implemented.
- During the construction phase, waste must be minimized. Coats, wastage, packaging as well as incorrectly ordered products, and surplus products must be limited as much as possible. Where it does occur, measures must be taken to utilize these resources.
- New products (incorrect orders and surplus products) must not be thrown away, these must either be returned to the manufacturer, or made available to internal and external stakeholders.

<u>Reuse of materials</u>

- In total, at least 50% of the components in the project (calculated by weight, ex ground, and foundation) must be reused or reusable per issues (3) and (4). It is up to the project to define the approach and distribution of different measures.
- In new buildings, at least 20% of the components (calculated by weight, ex ground, and foundation) must be reused, and reuse must be carried out for a min. 10 component types, defined as different building parts according to the building component table, 2-digit level.
- In rehabilitation projects, at least 50% of existing building structures must be taken care of (calculated by weight, ex ground, and foundation). Taking care of existing building structures counts as reuse in the reuse accounts. In addition, at least 10% of the components supplied to the building must be reused, and reuse must be carried out for min. 5 component types, defined as different building parts according to the building part table, 2-digit level.
- Local recycling of masses is in addition.

<u>Reusability</u>

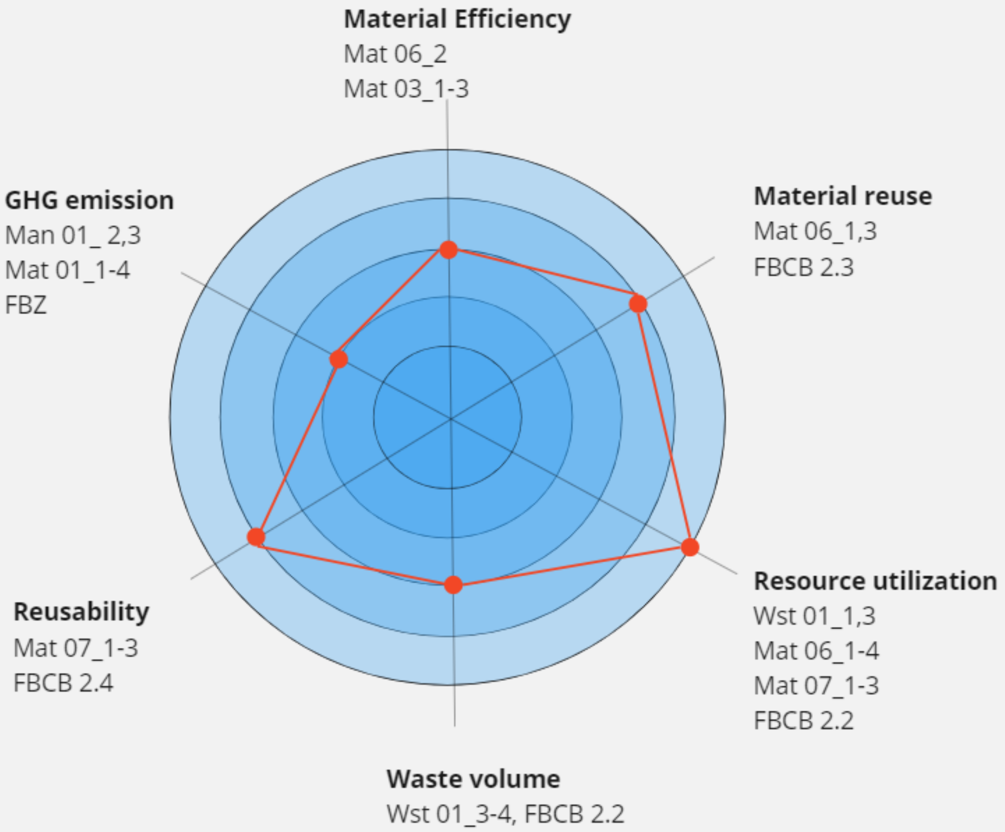
- In total, at least 50% of components in the project must be reused or reusable per issues (3) and (4). It is up to the project to define the approach and distribution of different measures.
- In new buildings, at least 20% of the components must be reusable, calculated by weight. Measures must be implemented for min. 10 component types, defined as different building parts according to the building part table, 2-digit level.
- In rehabilitation projects, 10% of the components that are added to the building must be reusable, and the measures must be implemented for min. 5 component types.

<u>Adaptability</u>

When designing circular buildings, it must be explained how strategies for changeability have been applied.

2.7.4 Corresponding points in the assessment methods

In FutureBuilt circular building criteria, there is a goal to raise awareness about circularity and for the criteria to be easy to apply. It is also a goal to link the criteria to already established Norwegian standards and guidelines (Nordby,2020). Based on this, FutureBuilt is currently trying to link its criteria to the BREEAM-NOR v6.0 criteria set which in its turn has included FutureBuilt criteria in their new version as an “Exemplary level" criteria (Green Building Alliance, 2022). Figure 2.19 is an illustration of an example of the reuse of building materials and products as a circularity assessment method based on the corresponding points between BREEAM-NOR v.06 relative criteria set for reuse and FutureBuilt s criteria for circular building and greenhouse gas emission Zero which need to be further discussed on future works.



- New BREEAM-NOR v.06 manual that emphasizes reuse today and for the future and relative following issues:
  - Man 01 Concept development and project optimization
  - Mat 01 Sustainable material choices - LCA and greenhouse gas calculations
  - Mat 03 Responsible procurement of materials
  - Mat 06 Material efficiency and reuse
  - Mat 07 Adaptability and Reusability
- FBCB : FutureBuilt criteria for circular buildings V2.0 16.03.20
  - 2.1Environmental-based decision on rehabilitation or demolition
  - 2.2 Resource utilization in demolition work
  - 2.3 Reuse of materials
  - 2.4 Reusability
  - 2.5 Adaptability
- FBZ: FutureBuilt ZERO - criteria for low-emission buildings and areas, V2.0 14.06.2021

Rating example for a building:

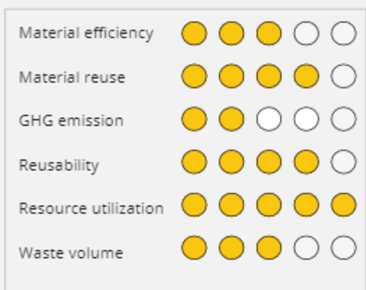


Figure 2.19: Reuse assessment and circularity indicators/parameters for building materials and products (self-produced)

2.8 Environmental system analysis

There are many different ways to estimate the environmental impact of building elements and building materials (Bakshi, 2019). Environmental system analysis can be used as a collective term for various types of environmental analyzes, among which is the life cycle analysis (LCA).

2.8.1 Life cycle assessment (LCA)

LCA is a systematized method used to determine the environmental impact of a product, product system, or activity through the identification of direct and indirect energy and material consumption, waste, and pollution to the environment (Bakshi, 2019). The analysis can contain all or part of the life cycle of a product or system, from the extraction of raw materials until the product is in use and is finally to be disposed of. The scope of the analysis, or system boundaries, is determined based on the purpose of the study. The method is based on the standards NS-EN ISO 14040, NS-EN ISO 144044, and NS-EN ISO 14025. Usually, carrying out a life cycle analysis follows the steps listed below.

<u>Definition of goals and scope:</u>

First, the goal and scope of the study must be determined. An assessment must be made of which processes are included in the product system and where the system boundaries should go. A common system boundary for building materials is cradle-to-grave, which includes all processes from raw material extraction to disposal. Cradle-to-gate refers to analyzes that only include processes until the product has been produced (SINTEF Building Research, 2014a).

Furthermore, a common functional unit is determined, which is a clearly defined and measurable reference unit. The functional unit links the product being analyzed to a function and a life cycle and should be able to form a basis for a fair and good comparison between alternative ways of solving the function (Bakshi, 2019; Fuglseth et al., 2018). It is noted that no functional unit can be determined for products that are only analyzed for parts of the life cycle (SINTEF Building Research, 2014a). Then declared units related to mass must be used, such as kg or m^3. A declared unit is not comparable in the same way as a functional unit (SINTEF Building Research, 2014a).

Overall, four main phases are often the starting point for determining the system limit for the life cycle assessment of construction products (SINTEF Building Research, 2014a). The phases are also represented in Figure 2.20.

1. The product stage deals with how raw materials are extracted and transformed into products. This includes phases A1-A3.
2. The implementation stage deals with transport to the construction site and the assembly of the building product in the building. These are phases A4 and A5.
3. The use stage involves the use, maintenance work, replacements, and operation throughout the life cycle. This involves phases B1 to B8.
4. The End of Life stage of the life cycle, phase C1-C4, deals with demolition work, dismantling, shipping, and disposal.

A1-3 Product Stage			A4-5 Construction Process Stage		B1-7 Use Stage							C1-4 End of Life				D Benefit s and loads
A1: Raw Material Supply	A2: Transport to Manufacturer	A3: Manufacturing	A4: Transport to building site	A5: Installation into building	B1: Use	B2: Maintenance (incl. transport)	B3: Repair (incl. transport)	B4: Replacement (incl. transport)	B5: Refurbishment (incl. transport)	B6: Operational energy use	B7: Operational water use	C1: Deconstruction / demolition	C2: Transport to end of life	C3: Waste Processing	C4: Disposal	D: Reuse, recovery, recycling

Figure 2.20: Overview of life cycle stages
Self-produced according to NS-EN 15978:2011 (Standard Norway, 2011)

Phase D is possible as additional information beyond the building's life cycle. This addresses the potential pros and cons of material and energy recovery, as well as further reuse (Standard Norway, 2006). It is worth noting that phase D is voluntary and intended as supplementary information, and is outside the current system boundaries. This means that the system only looks at a linear process from "cradle to grave" and not a circular way of thinking from "cradle to cradle" (van Dijk, Tenpierik and van den Dobbelsteen, 2014). If phase D is included, challenges arise in the distribution of advantages and disadvantages between different system delimitations (Nordby, Solli and Dahlstrøm, 2015).

Life cycle inventory phase

The life cycle accounting phase includes the collection of relevant data to be able to analyze resources that go in and out of the unit processes that are part of the product system. A unit process can be a simple work operation or an industrial process (SINTEF Building Research, 2014a). The resources can be materials, energy, waste, and emissions. The data collection can be extensive and detailed, depending on the type of analysis carried out. Databases are often used with the lifecycle inventory of several products and processes as a starting point for collection, such as Ecoinvent.

If emissions occur in activities that deliver more than one product, the emissions must be distributed between the various activities or processes. This is called allocation and can be implemented in different ways. The standards recommend trying to split the system into sub-processes as far as possible to avoid allocation problems (Fuglseth et al., 2018). If this is not possible, one can allocate by system expansion, or by distribution based on the physical size "mass, volume, energy" or economic value (Nordby, Solli and Dahlstrøm, 2015). The first mentioned involves "removing" by-products from a process by subtracting the emissions from the emissions of alternative production of the product.

Life cycle impact assessment phase

In this phase, the goal is to make visible the environmental consequences of the various input and output factors associated with the unit processes in the product system. Resource consumption and emissions are then assigned to different environmental impact categories or effect categories. Results of life cycle analyzes are most often stated in midpoint indicators, where emissions are assigned and classified into different environmental impact categories with the common name “impact categories”. According to the ReCipe[16] midpoint method (LCIA), which is widely used in LCA, a total of 18 impact categories are stated (Bakshi, 2018). Global warming potential (GWP) and acidification of soil and groundwater are examples of such effect categories (SINTEF Building Research, 2014a; Bakshi, 2018).

Each effect category has one common unit. For example, kg CO2 equivalents and kg SO2 are used for the mentioned categories, respectively. Several different emissions can contribute to the different effect categories. For example, carbon dioxide (CO2), nitrous oxide (N2O), and methane gas (CH4) contribute to global warming potential. To get all contributions on the same unit, characterization factors are used, which weigh the different emissions relative to each other (SINTEF Building Research, 2014a).

It is also possible to indicate results using endpoint indicators, which describe the consequences on, among other things, health, ecosystems or resource availability. This is not included in standards for life cycle assessment of buildings or building materials as these methods are more uncertain and subjective (SINTEF Building Research, 2014a).

Bakshi (2019) argues that it is important to have an overall system perspective when comparing alternatives to avoid one environmental problem being replaced by another (so-called "problem shifting") and to be able to find the overall most environmentally friendly solution in a societal perspective. By focusing only on greenhouse gas emissions, and in particular CO2 emissions, there is a risk of ignoring other environmental impacts of influence (Bakshi, 2019). Steinmann et al. (2016) nevertheless argue that some selected environmental impacts are in many cases most interesting and appropriate to highlight. Among them is GWP.

<u>The interpretation phase</u>
The last phase involves making an overall assessment when reporting and interpreting the results against the purpose and scope of the analysis. A critical review of an external third party may be necessary if the results of comparative analyzes are to be published (SINTEF Building Research, 2014a).

2.8.2 LCA of reused materials

When conducting a life cycle analysis that includes reused materials or products, there may be special considerations to take, compared to a standard newly produced product (Fuglseth et al., 2018). As mentioned earlier, the effects of reuse are only voluntary to include, and "cradle-to-grave" and "cradle-to-gate" are common system boundaries, so for the time being there are no special plans for conducting life cycle analysis (Richter, 2002).

Nordby, Solli and Dahlstrøm (2015) and Fuglseth et al. (2018) describe the allocation problem associated with material recycling, but which is also relevant in connection with reuse. The system under consideration is a recycling system where materials are used as an input factor in the production of new products. It is largely a matter of the advantages and disadvantages that arise from recycling or reuse, having to be allocated between projects. Fuglseth et al. (2018) state that the benefit of reuse in the form of reduced greenhouse gas emissions must be distributed to one or more of the use phases of a reusable product. Some selected methods will be described further.

[16] ReCiPe is a method for the life cycle impact assessment (LCIA). It was first developed in 2008 through cooperation between RIVM, Radboud University Nijmegen, Leiden University and PRé Sustainability. https://pre-sustainability.com/articles/recipe/

The method that is often used in EPDs is called "cut off" or "recycled share". It means that products are assigned the relevant environmental impacts that are directly associated with it. This means that the system that reuses a product will not get the negative loads from the production of the product. Another method, called "quality degradation", distributes environmental impact to each product concerning quality degradation or residual life. This gives manufacturers of long-life products an advantage. In a closed cycle, an average environmental impact from the production and disposal of all products in the value chain is distributed (Fuglseth et al., 2018; Nordby, Solli and Dahlstrøm, 2015). The methods see the use of resources in different products in one overall system.

If there is a product that remains in the building, for local reuse, it is recommended that the emission value is set equal to zero. If materials in the building are taken care of for reuse in the event of demolition, gains and emissions in connection with this can be set separately in phase D. Here, is considered the net environmental impact in connection with avoided emissions from the production of new materials and processing of reuse products (Fuglseth et al., 2018). For external reuse, the criteria are that the system boundary is set when the material from the previous system reaches "end-of-waste", defined following NS 3720. This means that the material must meet the following:

- It can be used for a specific purpose
- It fills a market need
- It meets legal requirements and other specific requirements
- It is not harmful to health and the environment according to REACH[17]

It is not clear when or how the materials reach "end-of-waste" and whether, for example, larger emissions associated with dismantling rather than demolition should be allocated between the systems or dedicated to one or the other project (Fuglseth et al., 2018). It is also not specified which phases are to be used if only the materials are considered, and not an entire building.

2.8.3 Methodological choices

When conducting life cycle assessments, there may be methodological choices that may have an impact on the final result. Here, choices regarding service life, and replacement needs will be described.

Assessment of the service life can have a major consequence on the final result in analysis because it affects periods for maintenance and replacement during the analysis period. The choice of the analysis period will also be decisive for what will be included. For buildings, the calculation period is often set at 60 years (Sintef Building Research, 2015). Rønning, Lyng and Vold (2011) emphasize that in life cycle assessments of building materials beyond load-bearing structures, the entire life of the building should be the starting point, as the service life of the materials are often complex and can be seen in context.

As mentioned earlier, different materials and elements in the building have a different service life that is affected by several factors, such as implementation, maintenance, material quality, and surrounding environment (Bjørberg, Kampesæter and Listerud, 2009). Lifespan is not an inherent characteristic and must be seen in the context of function over time. It will be the property that goes below an acceptable level of performance that is decisive for determining the service life (SINTEF Building Research, 2004b).

[17] UK registration, evaluation, authorisation and restriction of chemicals. https://www.hse.gov.uk/reach/

The establishment of a data basis for service life considerations has mostly been unsystematic and largely based on experience. Testing for short-term exposure in laboratories and long-term exposure under given conditions of use can help to give an expression of the product's durability. For evaluation of new products, it is often relevant to test for short-term exposure (SINTEF Building Research, 2004b). In general, a lack of information about exposure and current conditions of use for the products means that experience and expert assessments become central to longevity considerations (SINTEF Building Research, 2004b).

SINTEF Building research has prepared the instruction 700,320 "Intervals for maintenance and replacement of building parts", which includes proposals for short, medium, and long intervals, based on material quality and focus, for the technical functionality of building parts. These intervals are indicative, and it is recommended to take into account realistic adjustments based on available knowledge of the current application (SINTEF Building Research, 2017a, Bjørberg, Kampesæter and Listerud, 2009). This is also relevant for service life stated in EPDs that are based on the manufacturers' experiences, and not standardized test methods (EPD-Norway, n.d.-b). Stated service life should therefore be evaluated for choices in each case when using environmental declarations (EPD-Norway, n.d.-c), for both long service life and earlier replacement. An earlier replacement is usually since the functional service life has been reached because better solutions have come on the market or requirements from users and regulations have changed. Examples of which building parts and which service life is often applicable are shown in table 2.16.

The remaining life of a product will usually not decrease linearly over time but depends on what is due to the reason for replacement. In some cases, a further assessment should be made as to whether replacement is necessary at all, or whether repair may be relevant (SINTEF Building Research, 2017c).

Table 2.11: Overview of the service life that often occurs first in different parts of the building (Bjørberg, Kampesæter and Listerud, 2009).

Building parts	Service life is likely to occur first
2 Building	
21 Groundworks and foundations	Technical service life
22 Bearing systems	Technical service life
23 Outer walls	Technical or aesthetic service life (surfaces)
24 Inner walls	Functional service life*
25 Floors	Technical service life
26 Roofs	Technical service life
27 Fixture and fitting	Functional service life
28 Stairs and balconies	Technical service life
3 Heating, water and sanitation	
Pumps and aggregates	Functional service life due to requirements/technical
Pipes /channels	Technical service life
Electrical power	
Distribution	Technical service life/Functional
Light	Functional service life
5 Tele and automation	
Automation	Functional service life
Data system	Functional service life
Sound and image	Functional service life
Alarm and signaling system	Functional service life

*The company's function

2.8.4 Environmental declarations (EPDs)

The environmental profile of a component or product can be summarized in the form of an environmental declaration, the so-called EPD (Environmental Product Declaration). This is a concise third-party verified document that has been prepared based on a life cycle analysis (SINTEF Building research, 2014b). EPDs must be objective and standardized to enable comparison of the environmental impact of similar products, and design requirements are set under the ISO standard "14025 Environmental Labels and Declarations Type III" (EPD-Norway, n.d.-a).

There is an ever-increasing focus on sustainable material choices in construction projects and more people are demanding environmental declarations on the products. As the situation is today, there is still a way to go, as the EPD market is relatively immature, and well-documented materials can thus gain a competitive advantage (SINTEF Certification, 2020). According to Rønning, Lyng and Vold (2011), there is a weakness in the use of EPDs that it can be difficult to know which methodological choices and justifications affect the results, as this information is often not available.

3 Methodology

This chapter explains relevant methods used in the work on the master's thesis, with reasons for why the methods have been chosen. The chapter will ensure the validity and reliability of the thesis. First, the research design is presented in general, then the applied data collection methods and analysis method are described and evaluated.

3.1 The research design

The research design sets out a plan for how the research will answer the problem and research questions (Saunders, Lewis, and Thornhill, 2016). Thus, It refers to a systematic approach to increasing knowledge within a topic. The choice of research design depends both on the goal and the nature of the study.

The problem of the thesis is relatively twofold, consisting of:

1. Which building materials and products are suitable to reuse from a sustainability perspective?

2. What is the potential to increase the circular reuse of materials and accelerate the circular construction market?

Based on an extensive problem statement, it is considered necessary to consider the two parts as different objectives with a need for separate, but still overlapping research methods. The overall research method must address the study's overall problem. The selected method is illustrated in Figure 3.1.

For the first part of the problem statement, which deals with the environmental effect of reused components, it is considered appropriate to carry out a comparative assessment of case studies of a reuse-benchmarks/construction pilot project. Document study and literature review are mainly used as data collection methods for this part. Furthermore, data were also obtained through meetings and conversations with the project organization in the relevant case projects. The data is analyzed using an overarching life cycle analysis, and environmental system analysis. Findings from the document study and the environmental system analysis have been assessed against the literature.

In the work with the second part of the problem, it is considered inappropriate to include the case studies as this is a more general perspective. Here, it has instead been chosen to base the work on a combination of data collection methods. Qualitative reviews have been conducted which are assessed against literature from the literature study. Besides the document study of both FutureBuilt circular building criteria against BREEAM-NOR v6.0 criteria set for new buildings.

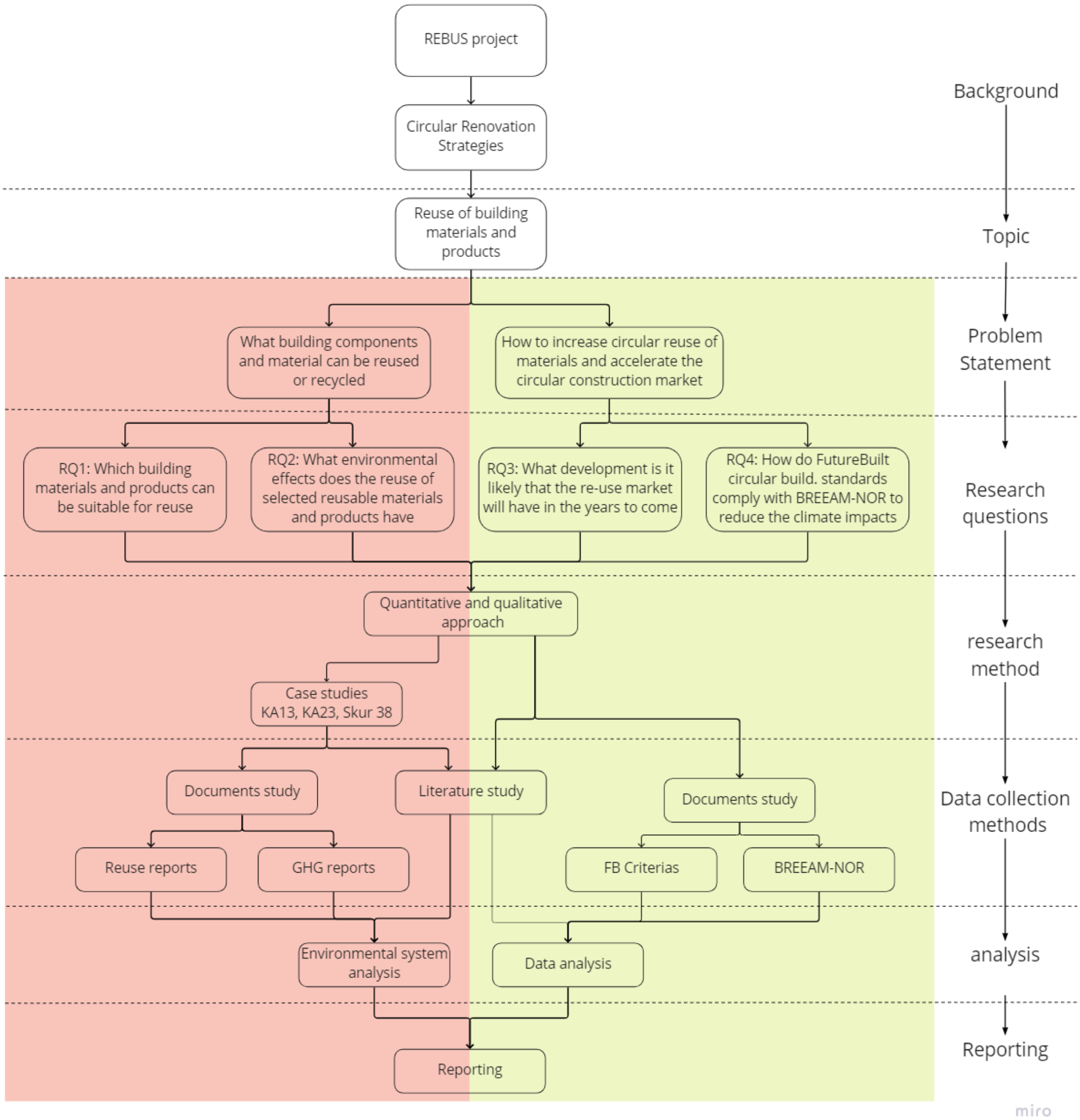


Figure 3.1: Illustration of the thesis' research method

Self-produced

3.1.1 Research methods

Overall, it is common to divide studies into qualitative and quantitative, as well as a combination of both. Simply explained are qualitative studies based on analyses and interpretations of the text, images, and statements within a topic, while quantitative studies analyze data and numbers. A qualitative study is often characterized by the fact that the information is based on fewer cases or occurrences, compared with a quantitative study that makes statistical studies of quantitative data (Saunders, Lewis and Thornhill, 2016). The methods will give different and complementary results, and it must therefore be considered which method is most appropriate in each case.

In this study, it has been chosen to combine qualitative and quantitative elements, as it has been considered appropriate to analyze both numerical data and qualitative information. Among the data collection methods, the document studies can mainly be regarded as quantitative, while the interviews and literature study are qualitative methods.

The thesis is based on a form of method triangulation "Mixed Methods", which involves combining several perspectives in the analysis (Saunders, Lewis and Thornhill, 2016). Theoretically, it is possible to divide into different forms of method triangulation, depending on whether the data is collected and analyzed in parallel or sequentially, as well as how different perspectives are included and combined. The method chosen in the study is described by Creswell (2014) as convergent parallel method triangulation "convergent parallel mixed methods", which involves a relatively simultaneous collection of qualitative and quantitative data. Collectively, the data will form a comprehensive analysis basis for answering the problem.

Method triangulation is often used with the assumption that a combination of different approaches and perspectives should be able to provide a more comprehensive understanding of the problem than using only qualitative or quantitative data (Creswell, 2014). However, chosen methods must work well together to contribute positively to the study (McLaughlin, 2012). This is considered in more detail in the chapter.

3.1.2 The nature of the study and its logical structure

The main purpose of the thesis is to investigate the potential for the reuse of materials and products and their environmental consequences in the construction industry. This is a relatively open and comprehensive angle, which requires insight into reuse issues and life cycle analyses. With such an interpretation, the nature of the study can be described as exploratory, as exploratory studies often seek to increase knowledge within a topic and understand contexts (Saunders, Lewis and Thornhill, 2016). This is also relevant for the second part of the problem, as it is desirable to explore the availability of reusable materials in existing buildings. Furthermore, to promote the circular reuse of building materials and products for an upscaling in the reuse market.

The first part of the problem seeks to investigate the actual environmental effect associated with the reuse of building materials compared with new products. This angle can to a greater extent be described as evaluative because it is desirable to evaluate how good the effect of reuse can give. According to Saunders, Levis and Thornhill (2016), evaluative studies are not only putting the spotlight on understanding "how effective" something is, but also "why". This also applies to the highest degree to the overall purpose of the study, which addresses "why" or "to what extent" it is appropriate to focus on reuse as an environmental measure. Overall, the study can thus be said to have a combination of an exploratory and evaluative nature.

3.1.3 Validity and reliability

Validity and reliability are common terms used to evaluate the quality of a study. Reliability says something about the reliability of the study and refers to whether another researcher could have followed the same procedure as the study and achieved the same results. Validity deals with the accuracy and quality of the study, whether procedures have been used appropriately and whether conclusions have been drawn on the correct basis. In other words, it refers to the credibility of the work (Yin, 2018). Subsequent subchapters will describe how validity and reliability are safeguarded and assessed in this study.

3.2 Literature study

To form a theoretical knowledge base for the entire thesis, a literature search has been carried out. Parts of the study are based on previous literature research carried out in many studies on the same topic. This work is supplemented by further search on environmental analyzes for existing building stock, as well as demolition activity. The literature study forms an important part of the information gathering through the work of answering the problem and the research questions. This method can further contribute to ensuring critical source use by systematic assessment of relevant literature (Aveyard, 2019).

In addition to what can be characterized as an academic literature study, supplementary searches have been made. This is to find relevant guiding documents, reports and other publications from relevant players that set guidelines and that can influence the reuse practice in the industry. It is noted that such documents, in the same way as the information obtained in the document study, are not necessarily peer-reviewed and verified as the literature found in the literature study. Therefore, it is especially important to evaluate the authors and the message from the documents. Examples of such relevant actors are the Ministry of Local Government and Modernization, Oslo Municipality, SINTEF, and the Directorate for Building Quality (DiBK).

As there is a lot of interest around the topic in the industry, and work that is going on these days, it has also been interesting to follow publications in various journals and professional publishing websites such as;Circulareconomy.europa.eu, Byggalliansen.no, Futurebuilt.no, Bygg.no, Innovative Anskaffelser, Fremtidens Byggenæring, and Teknisk Ukeblad and many others. This has inspired further work and insight into current elements within reuse.

3.2.1 Search strategy

It has been chosen to take the research questions as a starting point when searching for literature. Because the task is relatively twofold, it has led to a wide search field with great variety. The strategy for obtaining literature has at an early stage been to consult with supervisors about knowledge of relevant publications and master's theses.

Furthermore, the collection of literature is mainly based on systematic searches in academic databases on the internet. Current databases that have been used are Google Scholar, Oria, Elsevier, and Scopus. The keywords used can often give many hits, and to narrow down the searches, Boolean operators have been used as "AND" /"OR" functions. Synonyms and other intuitive keywords have also been used to find the most suitable sources. Examples of relevant keywords are shown in Table 3.1.

The searches were made in both Norwegian and English to increase the possibility of finding relevant literature. English searches yield several hits, but Norwegian sources are of particular interest as it is desirable to map the conditions and experiences that apply to Norway. Therefore, Norwegian searches have been given greater priority than English ones. In addition, in principle, only searches have been made for sources published in the last 5 years, i.e from and including 2014. This is to find updated and current sources, as well as reduce the number of hits. This exclusion criterion has nevertheless had to deviate for some of the search topics, as it has turned out to be less up-to-date literature.

Table 3.1: Examples of keywords used in the search databases.

Search words (English)	Search words (Norwegian)
• Reuse AND construction materials • LCA AND building materials AND reuse • Building stock AND material flow • Circular economy AND buildings	• Ombruk OG byggematerialer • Livsløpsanalyse OG byggematerialer OG ombruk • Eksisterende bygningsmasse OG materialstrøm • Sirkulær økonomi OG bygg

In addition to systematic searches, literature that has been evaluated and considered relevant has been used further as a starting point for chain searches. This is a method that is based on a review of the source's references, in the so-called "backward chain search". This has also been done by «forward chain search», which means going through publications that have referred to this particular source in their work (Rienecker, Jørgensen and Landaas, 2013).

3.2.2 Source evaluation

To ensure that the literature maintains quality and helps to build on the thesis' credibility, it is necessary to assess all of the literature. The assessment has been made several times to enable the exclusion of less suitable sources. In the first round, literature findings were judged based on the title and then keywords, summaries, and conclusions correlated with current research questions. Furthermore, the publisher and authors were assessed in more detail, and relevant sources were read more carefully. The TONE principle is used as a basis for this evaluation work. It is about ensuring the credibility, objectivity, neutrality, and suitability of the literature, see Table 3.2 (Breivik, 2017).

Table 3.2: Overview of the principles according to TONE and what it involves (Breivik, 2017)

Credibility	It is about evaluating who has published the article, where it has been published, institution affiliation, and whether it has been peer-reviewed.
Objectivity	Discusses the author's purpose with the publication and how data is presented; it must persuade or inform. It should also be considered whether the source sheds light on various aspects of the case.
Accuracy	Refers to the research methodology and how well it is explained, as well as whether the data is up to date and can be confirmed by other sources.
Suitability	Reflects relevance to the topic of the thesis and the problem, as well as whether the source can provide answers to the research questions that have been defined.

3.2.3 Strengths and weaknesses of literature study

Literature study as a data collection method can help to uncover a lot of relevant literature with good credibility according to set criteria. The use of several different databases can both help to find many good sources, and to evaluate the sources' credibility as the number of citations and publications in different databases can give an idea of how reputable they are considered to be. Within the topic of the thesis, there are especially some selected reports from Norway that are particularly relevant. These are frequently used, as they are extensive and include large parts of the theme.

Weaknesses of this method are that search results are highly dependent on how well the keywords are defined, and thus also dependent on self-expertise in the field. The keywords were defined by a combination of intuitive assessment of relevant words within the topic and by looking at keywords in the publications that were found. Other combinations of words and different uses of endings can give different results. This challenge is very relevant when searching for English literature, and there may be a reason to believe that relevant literature is omitted from the search.

The same keywords and phrases are used on all four search databases, sometimes with a large number of hits in some of the databases and a low number of hits in others. Some keywords can thus be considered too broad or too narrow in the various databases, which can go beyond the quality of the result. Google Scholar generally gives a lot of hits as this search engine does not have the same sorting features as the other databases. Some sources are found among the first pages of searches that yielded very many hits. Although the selected sources from such searches can be considered good, there is a danger that relevant sources placed on pages further back will be overlooked.

3.3 Document study

Obtaining information through document study has been necessary to be able to answer both parts of the problem. Document studies involve the collection, processing, and interpretation of secondary data (Jacobsen, 2015). In this study, documentation was obtained from both public and private actors. This applies to project-related information from the case study projects, as well as statistics and other data from Statistics Norway and the Oslo municipality at the Planning and Building Agency.

3.3.1 Case-study documents

Project-related documentation for the case projects includes project quality programs, reuse experience reports, greenhouse gas calculation reports including product declarations, and quantity descriptions. In carrying out the comparative environmental system analysis for the projects, there has also been a need for additional information about the materials and products in detail. As Kristian Augusts gate 13 is Norway's first building where the reuse of building materials and circular solutions has been used on a larger scale, and KA23 is Norway's first circular building with conservation status, the projects received great interest from the construction industry. FutureBuilt cooperated on their part of the projects to assign me a key contact person, who was my co-supervisor "Erlend Seilskær" during the whole work. He has obtained the desired information and was the bridge in contact with other relevant professionals and consultants in case study projects companies such as Multiconsult, Asplan Viak, and Green building alliance. etc. Thus, this information is passed on by the contact person on behalf of relevant professionals, manufacturers, etc. Thus, This study was built, among other documentation, on the following documents described below:

<u>Reuse experience reports</u>

The experience report has been prepared by the reuse teams on each project and was based on the feasibility study for reuse from the pre-project phase and experience reports from FutureBuilt workshops. It also discussed practical and technical possibilities and challenges in connection with the reuse of building parts in KA13 and KA23. Besides, substantiating conclusions regarding why and why not reuse has been possible. With the background on high environmental ambitions in the case study projects, early targets were set for a high degree of reuse of building parts, including specifically groundworks and foundations, load-bearing structures, and also exterior walls in existing buildings were mainly retained. Thus, the reports aimed to assess the reuse potential of building materials and components at their maximum ambition level.

Strategies and solutions for this have been adapted in the project in interdisciplinary processes where all disciplines have been involved. Initially, a large number of building parts were re-examined for reuse, and it has along the way lists have been prepared of procurement needs for used materials from other buildings. Professional advisers (ARK, RIB, etc.) have stated quantities and requirements specifications for these lists.

The reports were very informative about experiences over the implementation of a reuse project in all phases. From the pre-project to the implementation and completion of the project. Also the relevant experiences and learning points for each reused material and product category including the drivers and barriers currently in the construction industry, which highlighted in detail under the discussion section. It includes results about the material flow in the projects, from local reuse, external reuse, and disposal/sale materials in the form of tables and lists, which will be discussed further in the results chapter. For the KA 13 experience report refer to (Nordby et al. 2021), and for the KA 23 reuse assessment document no: 10213558-01-RIM-NOT-002, see Appendices 03.

Greenhouse gas emission reports

FutureBuilt's greenhouse gas emission reports are summary reports that explain their pilot project's environmental measures and results. It includes details about assumptions, data basis, measure assessments, choice of measures, etc. which is the basis for the greenhouse gas calculations and achieved greenhouse gas reductions. Generally, the greenhouse gas report has two goals; first, the documentation of calculations and calculation results of the greenhouse gas reductions, and second, spreading the knowledge to other projects about which assessments and measures have been carried out to reduce greenhouse gas emissions for the project. As well as, which assessment and measures have not been carried out. Thus, the reports are documentation of greenhouse gas calculations, achieved greenhouse gas reductions, and proposed and implemented measures. The reports are prepared and revised three times through planning/engineering, after construction, and after 2 years of operation. The calculations for Kristian August Gate 13 have been prepared by Asplan Viak AS, refer to Appendix 01, while the calculations for Kristian Augusts gate 23 have been prepared by Multiconsult AS, see Appendix 02.

As mentioned before, the goal of the greenhouse gas calculation is to shed light on the environmental effect of reusing materials, choosing new materials with low greenhouse gas emissions, mobility solutions with low greenhouse gas emissions and energy efficiency, and calculate greenhouse gas reduction for the project compared with reference buildings. The calculation is according to NS 3720: 2018 (Standard Norway, 2018) and includes greenhouse gas emissions from material use, transport, and stationary energy use.

For the calculation program for GHG calculation, in KA13, the calculations for greenhouse gas emissions from material use have been carried out in ByggLCA v1.1. Separate calculations have been made for transport based on RVU for Oslo and Akershus. Calculations for energy are based on Futurebuilt's emission factors for energy use and delivered energy calculated according to NS 3031: 2014 (Calculation of buildings' energy performance - Method and data) and NS 3701: 2012 (Criteria for passive houses and low-energy buildings - Commercial buildings). While in KA23, the online program One Click LCA

Previously" Bionova Ltd, 2021"[18] was used for greenhouse gas calculations. A separate spreadsheet is used for intermediate calculations that cannot be performed in One Click LCA. These intermediate calculations include conversion between units in the database and units that were to be used in One Click LCA, for example for material quantities in interior walls, and calculation of the number of visitors based on the number of employees.

3.3.2 Interviews

Furthermore, It has been decided to conduct interviews with relevant industry representatives to supplement information where there has not been sufficient information obtained through the literature and document study. Interviews are a widespread method in qualitative studies, which involve conversations with a given topic and structure (Tjora, 2021). Interviews can be conducted with a very formalized structure or as informal and unstructured conversations. In this study, it has been chosen to do informal and unstructured interviews due to time limitations and tight schedules for intended interviewees. This means that the interviews are relatively unstructured, but with some prepared topics and questions. Also with opportunities to make it more interactive and open up for discussion by letting the interviewees come up with their thoughts and input beyond the interview questions (Saunders, Lewis and Thornhill, 2016). This method of conducting interviews is well suited and is commonly used in exploratory and causal studies. So, the output of the interviews was decided to be used as a piece of supportive information in the case studies.

The interviews were conducted both physically and as online video calls using Microsoft Teams. This is partly because the digital interview has been easier to perform, and partly due to the Korona epidemic that was ongoing during the project period. The interviews have been performed as conversations and aim to close the gaps where there has not been sufficient information obtained through literature and documents and act as a supportive source of information for the case study documents. Following the interviews, the content is compiled by transcription. The content of the interviews is structured and then evaluated based on the thesis problem.

Many industry representatives have been interviewed with different competence and professional background. The answers from these interviews have contributed to the development of a level of knowledge that has been central to both the design of this thesis and to answering thesis questions. The interviewees were:

- Sigri Heen, BREEAM-NOR Consultant, Green Building Alliance
- Jennifer Lamson, Energy – and Environmental Consultant, Höegh eiendom
- Selamawit Mamo Fufa, Senior Research Scientist, SINTEF
- Pasi Aalto, Centre Director NTNU Wood and assistant professor, NTNU
- Julie Sandnes Galaaen, Environmental Consultant, Multiconsult AS
- Eirik Rudi Wærner, Environmental Consultant, Multiconsultant AS (the interview was not performed due to traveling circumstances).

3.3.3 Strengths and weaknesses of document study

The document study opens up the possibility of obtaining quantitative data that can be difficult to obtain in other ways. As this is not in all cases public information, it is important

[18] Bionova Ltd has changed its business name to One Click LCA Ltd, 1 July 2021 https://www.oneclicklca.com/bionova-becomes-one-click-lca/

that what is analyzed is reliable and correct, to the extent that it is possible to assess. According to Tjora (2021), it is important to ask questions about the context of the documents' origin and purpose. The information can be influenced by the author of documents written by and for who, as well as when they were written. In contrast to the literature collected in the literature study, these are not, to a certain extent, peer-reviewed documents that have been verified by external representatives.

Case-study documents

Parts of the information provided in connection with the case projects have been passed on by a contact person in the project, to avoid unnecessary action against the project organization. This reduces the ability to assess how the information is requested, and whether all relevant aspects are covered or disseminated correctly. As mentioned before, the experience reports were very informative about experiences over the implementation of a reuse project in all phases. But, the reports did not have the same degree of accuracy and comprehensiveness. For example, the KA23 report (see Appendix 03) specifies neither the learning points nor the quantities of local reuse and external reuse in detail. It was Höegh Eiendom who performed the reuse calculation but only as total amounts per Kg. It has been requested through the contact person to include in the report as done in KA13 the percentage of material flow in the KA23 project for the local, external and reusable materials and product weight percentages to be able to compare the case-study projects. This was provided as an external sheet, see Appendix 04. While in KA13 reuse report was more intensive, refer to (Nordby et al., 2021).

Greenhous gas emission calculation reports were extensive on the building parts level and included all the greenhouse emission calculations from material use, which is our scope of the study, and relevant CO2 savings, but it was limited to the material/product level. For example, KA 13 report specifies the greenhouse gas emission reductions only for some building materials and components, while in KA23 emission on material/product level was not clear enough. Besides, in KA 13 report, the GHG emission from material use calculation results for the "As-built building" (existing building+basement and the extension) were presented in detail in Appendix 2, while it was not presented for the reference building. Thus, the Greenhous gas emission calculation of the "Reference building" has been estimated on the material/product level to compare the results together. The case for KA23 was different, the report Appendix was not available and a datasheet collected from Multiconsult AS has the Greenhous emission calculations for both the reference and as-built buildings. Appendix 01 and 02 have the datasheets about Greenhouse emission calculations and reduction calculations re-documented and re-classified per the material/product level. The most challenging point through comparison performance was finding reused materials and products that fall under the same building category and gives a significant value to the comparison results.

Interviews

Interviewing is a time-consuming method, as it requires solid preparation before the interviews and processing afterward. The outcome of the interviews can be influenced by many factors. Among them, it can be pointed out that the wording or tone the interviewer uses when asking questions, as well as comments were given during the interview can affect how the interview candidate responds to the questions. The same can be said of the chemistry between the interviewer and the interview candidate, and whether the interview candidate has confidence in the study (Saunders, Lewis and Thornhill, 2016). Furthermore, it is important to note the role or position of the interviewee in connection with the study topic and how it affects the study.

As mentioned before, it has been chosen to do informal and unstructured interviews due to the time limitations of the study, long waiting times, and tight schedules for professionals and consultants This means that the interviews are relatively unstructured, but with some prepared topics and questions. This resulted in the interviews being more interactive and open up for discussion by letting the interviewees come up with their thoughts.

During the implementation, most of the interviews have not been recorded by voice recording but important comments and reflections were noted down, which ensures that all interesting points are perceived and included. On the other hand, it means that some of the interviewees become particularly more expressive than aware of what information they are communicating and that they choose to share more than in a formal conversation.

Semi-structural interviews open up the possibility of following up with additional questions if the interviewee says something particularly interesting. This is seen as positive, as it opens up new understanding and learning. On the other hand, the interviews are largely governed by how complementary the interview candidate answers questions, and interviews with the same interview template can be very different. A lack of standardization of the interviews can thus lead to a low validity.

3.4 Case studies

The case studies have been chosen as the overall research method for answering the first part of the thesis problem when conducting a comparative environmental system analysis. The research method is further based on several different data collection methods, to find sufficient data to analyze and ensure the validity of the study.

According to Yin (2018), case studies often focus on events or cases from the present and explore a phenomenon or case in-depth within a realistic framework. A case study can analyze one or more cases. The chosen case projects were FuturBuilts pilot projects; Kristian Augusts gate 13, Kristian August 23, and Skur 38 in Oslo representing the most significant benchmark- and large-scale reuse projects in Norway. As mentioned in the introduction the third project "Skur 38" was excluded from the comparison analysis due to the lack of reuse datasheets and relevant greenhouse gas emission reports as well as using a different greenhouse gas calculation methodology than performed in KA13 and KA23. The last-mentioned case projects were therefore considered appropriate in this study. The projects have been chosen based on their topicality and reuse ambitions, in addition to having appropriate progress concerning the period in which the master's thesis is written.

3.4.1 Presentation of case studies

KA 13

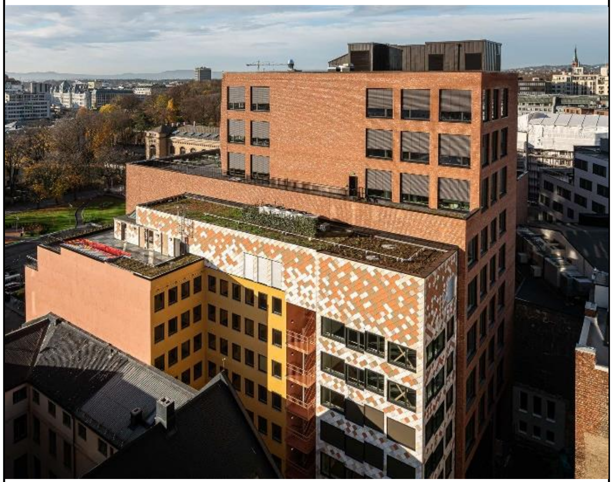


Photo: Mad Architects / Kyrre Sundal

Kristian Augusts gate 13 is Norway's first building where the reuse of building materials and circular solutions has been used on a larger scale. With up to 80% reuse of materials, Kristian Augusts gate 13 has reduced greenhouse gas emissions by 70%, and the project has made reuse a theme for the entire construction industry (FutureBUilt, 2020).

Location and period: KA 13 is located at Tullinsløkka in Oslo and is originally an 8-storey office building (including basement) built in the 1950s. According to circular principles, the rehabilitation and upgrade of the existing building was carried out as well as the construction of a new extension of 8 floors with a floor area of approx. 60 m². It was built in the period 2018-2020 by Entra as developer, and the first year of operation was 2021.

Reuse: In the construction of the extension, work is being done on reuse to a large extent at the same time as the extension complied with the requirements in TEK 17. Within circular principles, work has been done on reusing building parts from the existing building (eg load-bearing system, radiators, restoration of interior surfaces) at the same time as the project will reuse building components from other projects (eg steel, hollow-core slabs, sanitary equipment, facade panels, radiators, doors, glass facades etc.) (FuturBuilt, 2020).

KA 23

Photo: Dimitry Tkachenko

Kristian August Gate 23 is Norway's first circular building with conservation status. It has been rehabilitated according to sustainable principles, and follows FutureBuilt's set of criteria for circular buildings. With up to 88% reuse of materials, Kristian August Gate 23 has reduced greenhouse gas emission by 55% (FutureBuilt, 2021).

Location and period: KA 23 is located at Tullinsløkka in Oslo and is originally an office building built in 1951 as the headquarters of the Norwegian Employers' Association. The building has been rehabilitated by Höegh Eiendom. The project period ran from 2020 to 2022. The project aims was to become a circular building according to FutureBuilt's criteria.

Reuse: The building consists of over 50% reused and reusable materials and components. The facade of the building is protected in accordance with the Planning and Building Act, and existing foundations, load-bearing structures, exterior walls, window frames, floors, load-bearing system, stairwells, lifts, parts of interior walls and some technical equipment are retained. An extension in new materials has also been built (FutureBuilt, 2021).

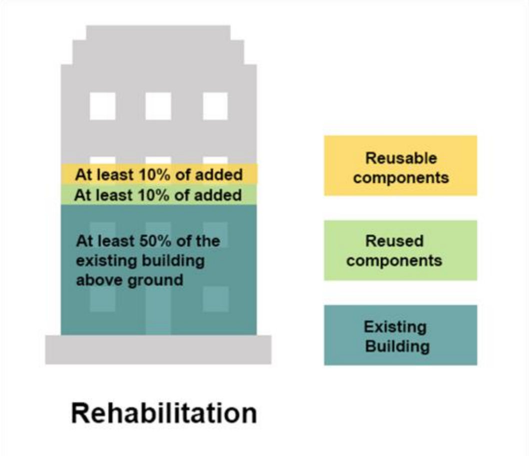
KA 13

Area: The building including the extension has a gross area (BTA) of 4,762 m², of which the extension amounts to 857 m², and a heated usable area (heated BRA) of 4,050 m². 194 employees are planned as regular users of the office building(see Appendix 01).

Project team:

- Developer: Entra ASA
- Original architect: H.J.S. Bakstad Arkitekt
- Architects: MAD architects
- Project & const. management, environmental consultant and reuse coordinator: Insenti AS
- Main contractor: Haandverkerne
- Adviser const. engineering: Rambøll AS
- Energy & reuse advisor: Asplan Viak AS

Goal/ambition: In its criteria set for circular buildings, v. 2.0, Futurebuilt has defined the following quantitative requirements for reuse and reusability (Nordby, 2020).



GHG reduction min. 50% .... 70 %
Reusability min. 10% 15%
Reuse min. 10% 80%

The project should facilitate resource utilization at the highest possible level that at least 50% of existing building structures are taken care of and that at least 10% of the components supplied to the building must be reused.

Achieved: 80% reuse (80% local reuse, 15% from donor buildings and 3% reuse and reusability (of total weight)), 70% reduction of CO2 emissions from production of building materials (Nordby et al., 2021).

Status: completed

KA 23

Area: The building including the extension has a gross area (BTA) of 8,962 m², of which the extension amounts to 226 m², and a heated usable area (heated BRA) of 8,721 m². 413 employees are planned as regular users of the office building (see Appendix 02).

Project team:

- Developer: Höegh Eiendom
- Original architect: Bjercke & Eliassen
- Architects: Arcasa architects AS
- Project management : Stig A. Nilsson
- Construction management: KPP AS
- Main contractor: Seltor AS
- Energy & reuse advisor: Muticonsult Norway AS

Goal: Retain the building's original character features and meet FutureBuilt's criteria for circular buildings v.2.0. So, the following quantitative requirements for reuse and reusability were identified.

GHG reduction min. 50% .... 55 %
Reusability min. 10% 53%
Reuse min. 10% 88%

The project should facilitate resource utilization at the highest possible level that at least 50% of existing building structures are taken care of and that at least 10% of the components supplied to the building must be reused.

Achieved: Preliminary results show 88% reuse, 3% from donor building and 53% reusability, approx. 55% greenhouse gas reduction compared to a reference project and 30% waste reduction (see Appendix 04)

Status: completed

Materials/products and Buildings' structure

The existing building of KA13 is a concrete building with load-bearing columns and beams and concrete floors. Central to the building is a continuous staircase and elevator. The facade facing Kristian August gate13 is clad with stone panels. The extension consists of load-bearing steel columns and beams and hollow-core slabs in concrete. The facade is composed of different types of sheet metal and cement cladding (FutureBuilt, 2021).

Figure 3.2: Kristian August gate 13 - existing building (Elverum, 2020)

Kristian Augusts gate 23 was built in 1951 and rebuilt around the year 2004. The building consists of 8 floors and a basement with a footprint of approx. 1200 m². The building is built with concrete in the foundation and floors, and walls of brick and some LECA. The facade towards the street level consists of panels of natural solar stone (solvågstein) as facade panels and original teak windows. Inside, the entire eighth floor as well as some corner offices are original with characteristic teak and marble walls. It has been a goal to retain as much of the building's uniqueness as possible, both for reasons of the environment and architectural value. The building has been restored based on FutureBuilt's set of criteria for circular buildings (FutureBuilt, 2022).

Figure 3.3: Kristian August gate 23 - existing building
(Wikimedia commons, 2014; Estate news, 2019)

Scope of reuse in the projects

The Scope of reuse in a pilot project is defined according to FutureBuilt as three different Material flows, as illustrated in figure 3.4. Case study projects implemented the following types of reuse:

Internal reuse:

In KA13, different building parts and materials are reused locally in the project, such as doors, radiators, wood panels railing, air ventilation, cableways, and fixtures. In addition, the load-bearing system from the existing building is retained. This is not directly referred to as reuse as it is not moved, but it contributes to an increased service life of the materials/products and high resource utilization (FutureBuilt, 2021). While in KA23, The facade of the building is protected under the Planning and Building Act, and existing foundations, load-bearing structures, exterior walls, window frames, floors, load-bearing system, stairwells, lifts, parts of interior walls, and some technical equipment are retained. Original wood panels, polished plaster walls, stairs, terrazzo floors and internal walls, exposed concrete columns, window screens, doors, and other technical equipment such as pumps, snow-smelting plants,.etc (FutureBuilt, 2022).

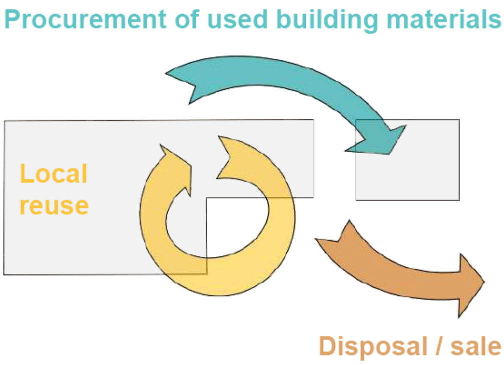


Figure 3.4: The three different materials flow

(Nordby et al., 2019)

External reuse:

In KA23, materials have been brought in from other donor buildings. This type of reuse is most common in the extension, and here, among other things, steel, hollow-core slabs in concrete, sanitary equipment, and façade elements have been reused. While in KA23 the external reuse was limited to used-brought items/added items and leftover ceramic tiles (from KA 13), wardrobes, benches, and AHU (air handling units).

Disposal/sale:

In KA13 disposal of used building materials has not been relevant for many items. Most of what was usable in existing buildings were reused in KA13. A stack of 4x4 inch beams from the existing part was given away to the company "Drivved". Furthermore, some surplus materials from KA13, including old teak doors from stairwells and some used doors from the 6th floor, were taken care of by Entra for possible use in the neighboring building KA11. There is also some surplus of acquired, used items. If Entra does not find a use for it, it may be relevant to dispose of via a third-party player. While in KA23, glass and door panels, catering kitchen machines with counter and canteen accessories, a total of 8,147 kg were retrieved by Bruktrom company. Of this is reused and further sold approx. 95%. Besides, it was delivered 324.34 tons of pure bricks to "Østfold gress" by Seltor AS from the project to be reused.

Reuse process

The investment in reuse has led to the project's construction process being set up a little differently than a conventional project model. It is noted that as of today, reuse processes are still being clarified or have not been carried out, so this is a general presentation of the process. An overview of the reuse process is illustrated in Figure 3.6.

The search for reusable materials began already in the pre-project stage and continued into the detailed design and the construction phase (Elverum, 2020). Both architects, contractors and reuse consultants have helped to find products and solutions for reuse (FutureBuilt, 2020). External industry representatives have also helped to find solutions, for example, in KA13, through interdisciplinary workshops organized by Entra in collaboration with FutureBuilt. . Used building materials come from over 25 buildings, which have been in the demolition/rehabilitation process or where building parts have been used temporarily. The illustration below shows where the nearest "donor buildings" are located.

The mapping and logistics related to reuse products are described as time-consuming, and thus cost-driving for the project (FutureBuilt, 2021). Decisions have been made in several rounds when procuring used materials, and in some cases, reuse has led to changes in the design. The reused materials have had different needs for intermediate storage, processing and testing, which requires planning and logistics. Own lawyers are engaged in the project to take care of the regulations related to the reused products. Figure 3.5 presents the different project locations where reused materials were retrieved to KA13. While the reuse process according to pilot projects' experiences is presented in Figure 3.6, from project reuse mapping phases through documentation and selective demolition/disassembly to assembly and use.

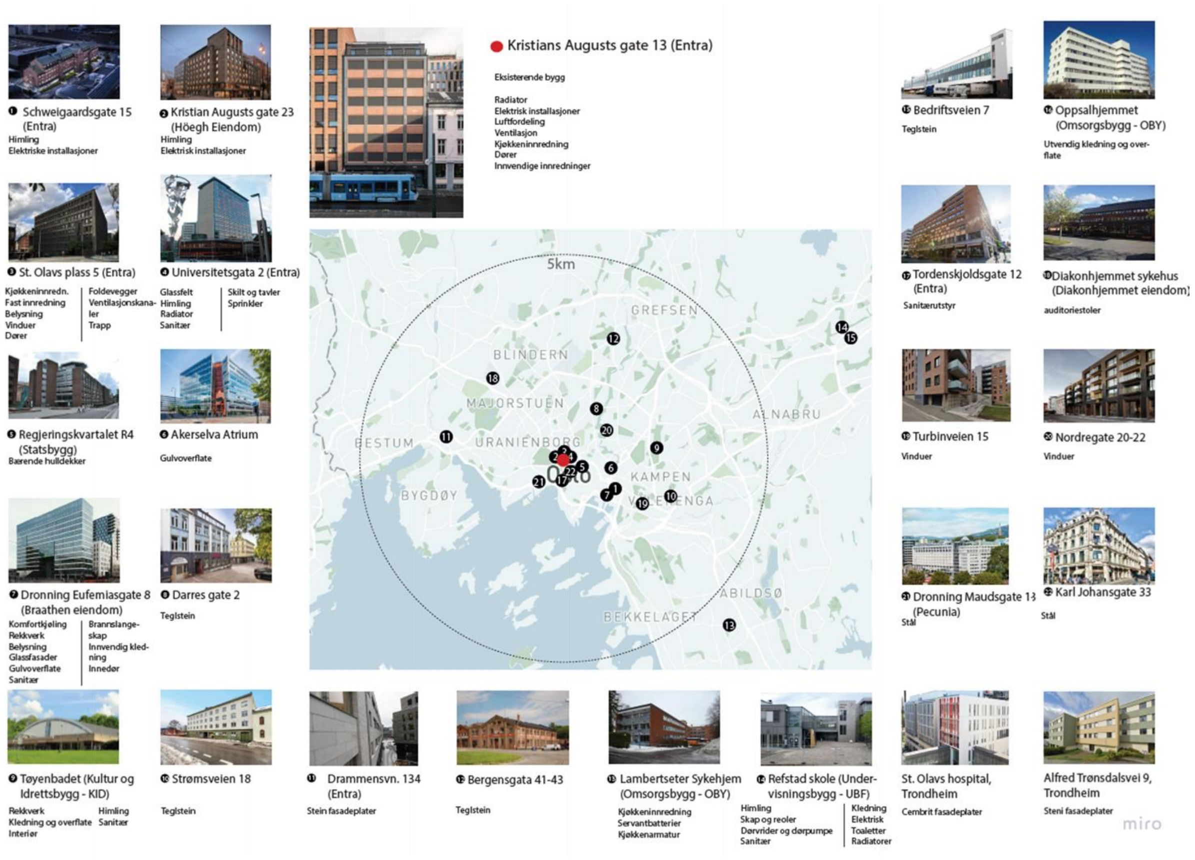


Figure 3.5: Overview of locations for the analyzed reused products were retrieved to KA13, Illustrated by Mad Architects .

(Nordby et al., 2019)

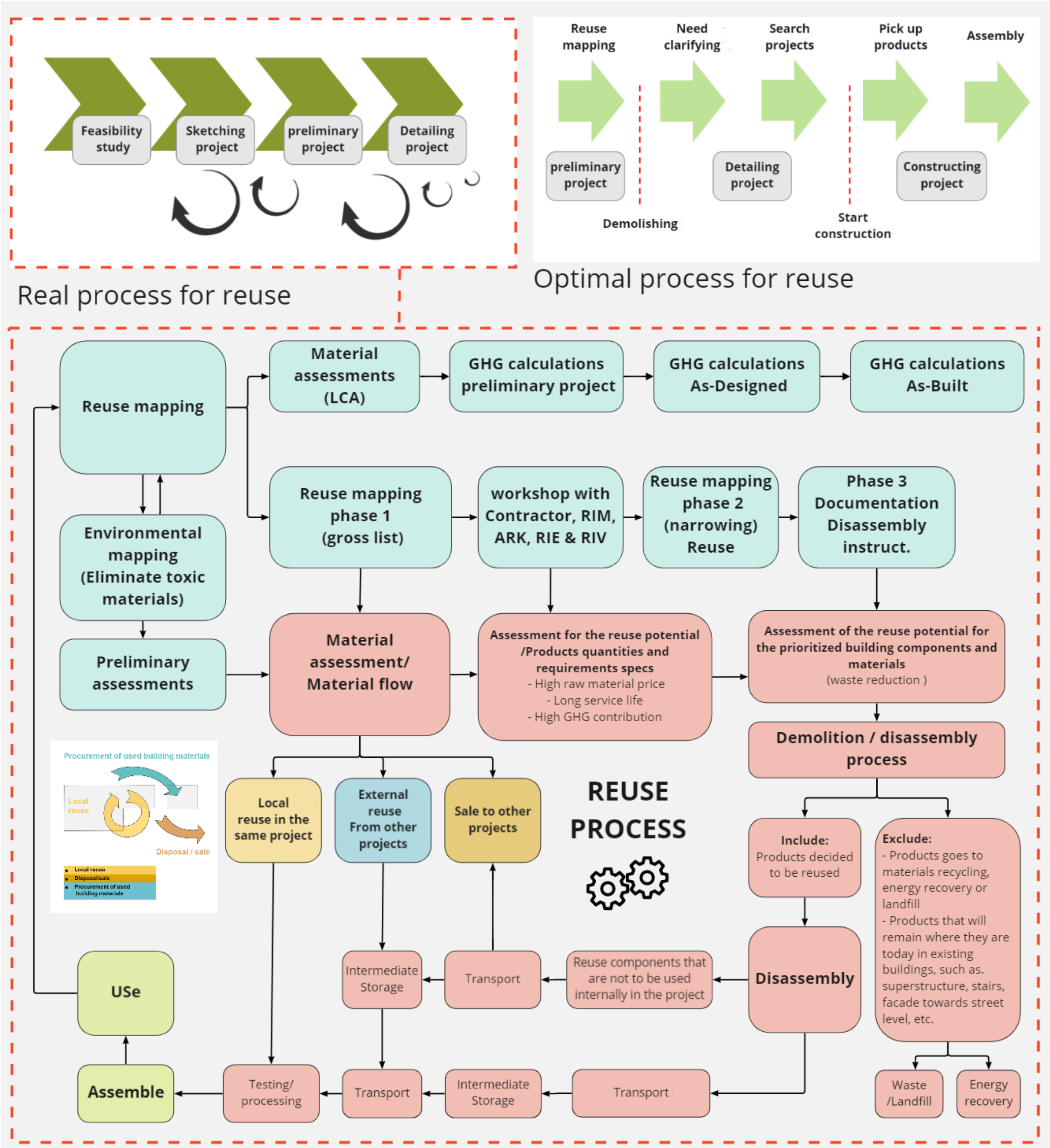


Figure 3.6: The reuse process according to case projects (self-produced)

3.4.2 Strengths and weaknesses of the case studies

A good case study is often based on several different data acquisition methods (Yin, 2018). This opens up the possibility of verifying data from the various methods used, and will be able to increase the study's reliability. In this study, method triangulation opens up for statements in informal interviews to be compared and checked with data obtained from document studies as well as information from literature found in the literature study.

A possible weakness of a case study as a research method is that it has been debated whether results from case studies can be generalized and used to create credible theory (Yin, 2018). Yin (2018) points out that case studies can try to generalize analytically and not statistically, which is based on a large number of cases. It is further emphasized that generalization must be carried out based on the case study and not the specific case.

Theory and literature must therefore in this case play an important role for it to be possible to generalize the results. The procedure and method used to analyze the case are described in the next subchapter.

3.5 Environmental impact assessment

An environmental system analysis is the method used in connection with the assessment of the environmental impact of selected materials/products associated with the case study projects KA13 and KA23. The analysis is based on data obtained through document study and literature study, as well as supplementary information obtained through interviews with representatives from the project organization and relevant professionals.

An environmental system analysis is, as described in the theory chapter, a form of life cycle assessment. This term is used to emphasize that a complete LCA is not carried out with the inclusion of detailed inventory analysis. Nor is any assessment made of environmental impacts other than Greenhouse gas emissions. The implementation of the environmental system analysis nevertheless follows procedures given in the standards for LCA as far as possible. (System boundary A1-A3+B4-B5 as per NS3720).

The environmental system analysis carried out in this study is comparative, where greenhouse gas emissions related to the processes for implementing reused materials are compared with corresponding new materials. The analysis is based on five different material groups/products with reusable products used in the project, as shown in Table 3.3. It has been chosen to focus on the comparison of selected and disregard other materials and products in the rest of the two buildings.

3.5.1 Goal and scope

The overall objective of the GHG calculation is to shed light on the environmental impact of reused materials compared to similar new materials, select new materials with lower GHG emissions, and calculate the project's GHG reduction compared to reference buildings. The aim is to find out the environmental benefits associated with the reuse of the selected categories of materials/products, as well as to highlight other unexpected consequences that may affect the results. Besides spreading the knowledge to other projects about which assessments and measures have been carried out to reduce greenhouse gas emissions, as well as which measures have not been carried out or have been chosen not to carry out.

A comparative environmental impact analysis was conducted at the level of building parts to show the benefits of the reduction from a general perspective, and then more specifically at the material/product level, following the specific relative material classes in detail. Furthermore, the material/product categories in the analysis were selected in collaboration with representatives from the case projects, based on materials and products that could be considered interesting from an environmental perspective, as well as the availability of information after the projects were completed. It is assumed that the materials will satisfy the same function used and that the total amount of new alternative products is similar to the quantities reused. The calculation is according to NS 3720: 2018 (Standard Norway, 2018) and includes greenhouse gas emissions from material use, transport and stationary energy use.

Functional unit

The functional unit is generally defined as a given amount of a product, which performs its function throughout the system period, which is set to 60 years. It is natural to use a different unit for each product as the quantities are defined differently. The relevant units for each material are given in Table 3.3. The units shall be the same for the reused material category and the corresponding new alternative to ensure a basis for comparison.

Table 3.3: Overview of selected material categories and the associated functional unit used in the analysis

Material/ product Category	Functional Unit
Steel	1 kg of steel for load-bearing use for 60 years.
Hollow-core slabs in concrete	1 ton of hollow-core slabs as a load-bearing cover between floors for 60 years.
Brick	1 m^3 of brick for 60 years
Windows and doors	1 m^2 of windows and doors, through 60 years.
Façade cladding	1 m^2 of facade panels for 60 years.

System boundary

According to FutureBuilt's greenhouse gas emission reports, it has been chosen to use an analysis period of 60 years. This is standard for the FutureBuilt pilot projects and 60 years is often used in life cycle assessments (Fuglseth et al., 2018). Because the analysis is comparative, it has been chosen to disregard processes and phases that are assumed to be approximately the same for reused and new materials. Phases included in the analysis are A1-A3 and B4. Figure 3.7 shows an illustration of which processes are included in the system boundary, which is marked with a dotted line. The figure includes two product systems; one for reused products and one for new alternatives.

For the new materials that are not replaced during the service life, it is mainly the production of materials (A1-A3) that are included. End of life phase is then not included in the system limit. The same applies to the reuse materials, but phases A1-A3 will instead of extraction and production involve disassembly, testing, and intermediate storage as well as transport and necessary processing. Disassembly is included from previous projects, as it is assumed that it would have been dismantled or demolished in another way if it had not been planned for reuse. Transport for intermediate storage and processing has been chosen to include in phases A1-A3. The last transport stage A4, to the construction site, is not included to maintain the comparison basis.

Assembly (A5) is not taken into account, because there are significant differences between new and reused. Maintenance (B2), repair (B3), and renovation (B5) are not included, as it is assumed that there are minor differences, in addition to the fact that there is not sufficient information to be able to make a qualified assessment of the need for maintenance during the analysis period. If the material is replaced (B4), all emissions related to the handling of the replaced product (A1-C4) shall be assigned to phase B4, as per the system limits given in NS 15978.

In calculations associated with the reusable materials, it has been chosen to include input data from processes that can be connected directly to them. This applies to energy consumption from processing, intermediate storage, and testing where this is relevant. Production and transport of additional products for processing are also included. On the other hand, the environmental impact from the actual manufacture and production of machines and equipment used in the processes has been chosen to be disregarded, as it is assumed that the products last a long time and it will not make much difference to include contributions that would be allocated to these processes.

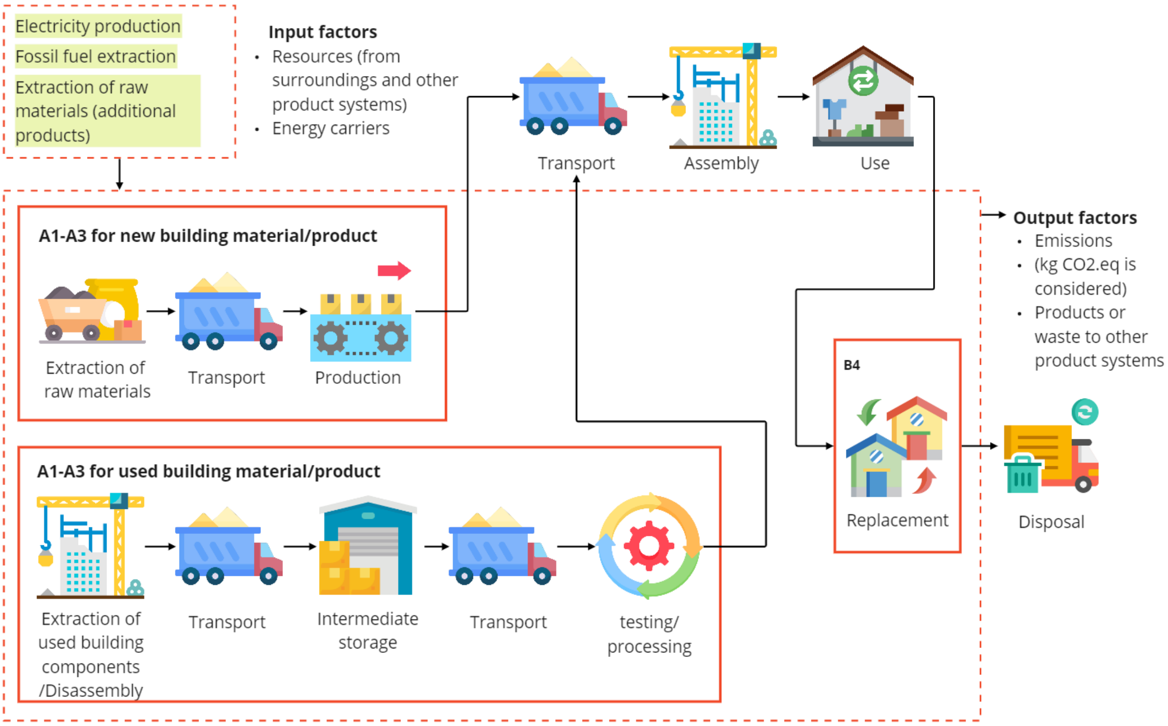


Figure 3.7: Flow chart for analyzed material/product system. The system boundary is marked with dotted lines A1-A3 and B4 (self-produced)

3.5.2 Life cycle inventory

Knowledge of the materials and products used and of the whole process is central to being able to carry out the analysis. This requires extensive data collection for relevant processes and phases that are included.

Collection of data

Information about the materials has largely been obtained during document study, and current documentation has been sent directly from the project's contact person. Furthermore, information has also been obtained in communication with project teams consultants, and professionals or the use of databases for specific product information.

There have been regular meetings with the contact person who is my co-supervisor from FutureBUilt, to discuss and coordinate assumptions and hypotheses for all materials in the analysis. Where there has not been sufficient information, it has been seen necessary to make separate assumptions to obtain numerical values. This applies in particular to the calculation of KA13 reference building production and disassembly. Where emission data for reusable materials have not been available, a standard reduction of 80% in phases A1-A3 has been used instead. An overview of the calculations for Kristian August Gate 13, originally prepared by Asplan Viak AS, is gathered in Appendix 01, while the calculations for Kristian Augusts gate 23 originally prepared by Multiconsult AS, are collected in Appendix 02.

Data tools and databases

As mentioned before and according to Greenhouse calculation reports, the reference building of KA13 is generated in carbon designer in OneClick LCA and adapted to be more representative through the Enova report « Climate-friendly building materials - Potential for emission reductions and barriers to use » (Asplan Viak, 2020) while the as-built taken from BIM model, dated 16.09.2020. The calculation program for GHG calculation from material use, in KA13, has been carried out in ByggLCA v1.1 (see Appendix 01). While in KA23, the online program One Click LCA (Bionova Ltd, 2021) was used for greenhouse gas calculations. A separate spreadsheet is used for intermediate calculations that cannot be performed in One Click LCA. These intermediate calculations include conversion between units in the database and units that were to be used in One Click LCA, for example for material quantities in interior walls, and calculation of the number of visitors based on the number of employees. Adapted reference building was prepared in April 2020, based on the IFC model downloaded 16.03.20 (see Appendix 02).

3.5.3 Strengths and weaknesses of environmental system analysis

In general, there is uncertainty associated with obtaining information and the quality of the data (Thormark, 2000). It is relevant for the calculation of quantities, equipment, and emission factors used in the analysis. In several cases, data is retrieved on similar products and not specifically for the particular product being analyzed. This may mean that the results and the actual emissions do not match. However, this is difficult to verify.

Compared materials/products

A challenge in comparative analysis is the assumption that used and new materials fulfill the same functions and that the phases in which they behave similarly are excluded from the analysis (Rønning, Lyng and Vold, 2011). This is a simplification, and whether this is the case, in reality, is linked to uncertainty. It is important to note that the results from a comparative analysis only give a picture of the difference in the environmental impact between reused and new materials, and not complete emissions related to the entire life cycle of the materials. There are several processes with associated emissions that have been disregarded, and which in reality would have contributed CO2 and a greater environmental impact than what is calculated. For some of the reuse materials, , a conservative estimate of 80% reduction concerning new material has been used, after consultation with Futurebuilt , professionals and climate consultants in the industry.

System boundary

The system boundary is relatively broad, and it can be difficult to know where the included phases in the analysis were proper and what can affect the result to a greater extent. Exclusion of processes that contribute with insignificant contributions can be challenging to predict, and therefore considerable time was spent on the analysis. What is included in processes also completely depends on what information has been available from the given projects. Thus, some contributions are calculated in great detail, while other processes are estimated.

4 Results

4.1 Comparative environmental analysis per Building part

4.1.1 Overall results

KA 13

Asplan Viak AS has prepared a greenhouse gas account for the entire KA13 project according to FutureBuilt criteria for circular building, including emissions from energy, material use, and transport.

1. The total GHG reduction was of 40% compared with the reference building. The greenhouse gas emissions for the project "as built" are estimated at 39.38 kgCO2eq./m2/year, and 822 kgCO2 eq./occupant/year. In total for the building, this amounts to 159,473 kg CO2 eq./year.
2. The project has been compared with a reference building with the same area as KA13 (BRA of 4050 m²), but which has been built new with conventional material use. The extension part (tilbygg) of the building was included in the reference model.
3. **CO2 Saving**: The calculations show that emission reductions from material use of 70% or (6.45 kgCO2eq./m²/year) are achieved for the whole building, i.e., both the rehab part and the new building, see figure 4.1. For the existing building and basement, emission reductions of 78% are achieved compared with the reference building, and for the new building, emission reductions of 36% are achieved.

KA 23

Multiconsult AS prepared the GHG accounts for KA23 project according to FutureBuilt criteria for circular building, including emissions from energy, material use, and transport.

1. Kristian Augusts gate 23 achieves a greenhouse gas reduction of 55% compared with reference buildings. Reuse of materials, use of materials with low greenhouse gas emissions, reduced energy consumption, use of district heating, central location and no parking contribute to reducing greenhouse gas emissions in the project.
2. The project has also been compared with a reference building with the same area as KA23 (BRA of 8721 m²), but which has been built new with conventional material use. As the building has a protected status, all the protected elements including the fasade toward Tullinsløkka street were excluded from the reference building. The extension part (påbygg) was included in the reference building.
3. **CO2 Saving**: The calculations show that for the project compared to the reference calculation, an emission reduction, for the material use, of 85% is achieved for projected and 83% or (3.57 kgCO2eq./m²/year) for "as built". Refer to figure 4.1.

4. **Why?** The main reason for the reduction in greenhouse gas emissions is that existing building mass and load-bearing systems have been preserved. There is also a high degree of reuse in the extension, which leads to a reduction in greenhouse gas emissions. For the existing building, much of the building body has been preserved, which provides major reductions for load-bearing systems, exterior walls, roofs, and floors.

Existing foundations have also been preserved, except for the floor to the ground which is included in the decking. This means that the existing building has very low greenhouse gas emissions compared to the reference building. The comparison of CO2 saving per Kg CO2.eq/m²/year by building elements is shown in figure 4.2.

4. **Why?** Greenhouse gas emissions from materials have been reduced from reference buildings to projected buildings and "as built" due to a large degree of reuse and preservation of materials as well as the use of materials with lower greenhouse gas emissions than the reference values.

The largest reductions are achieved for Groundworks and foundations, exterior walls, floors and load-bearing systems, and for these building parts there is a high degree of reuse in the project. For interior walls, the reduction in greenhouse gas emissions is not so great due to the significant amount of new interior walls in the project. GHG emissions have increased somewhat for stairs and balconies, mainly due to the steel stairs under the green-house, which in the reference building are modelled as concrete. The comparison of CO2 saving per Kg CO2.eq/m²/year by building elements is shown in figure 4.2.

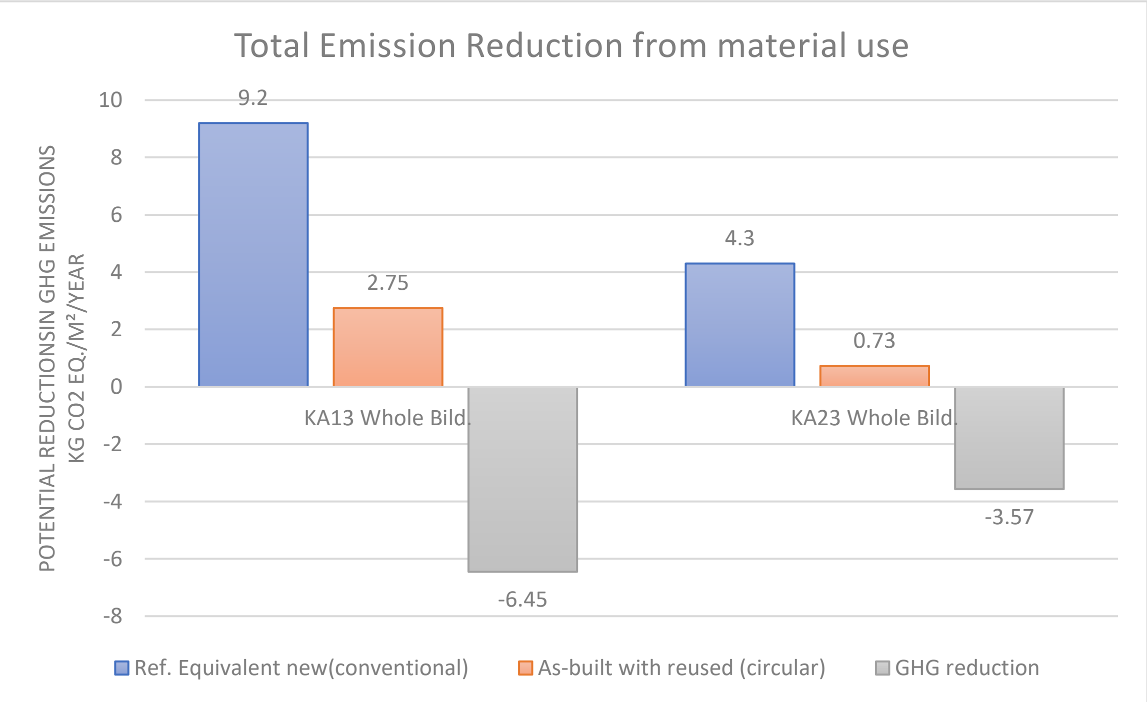


Figure 4.1: Comparative GHG emission reduction from material use for different project phases for the entire building, KA13 and KA23.

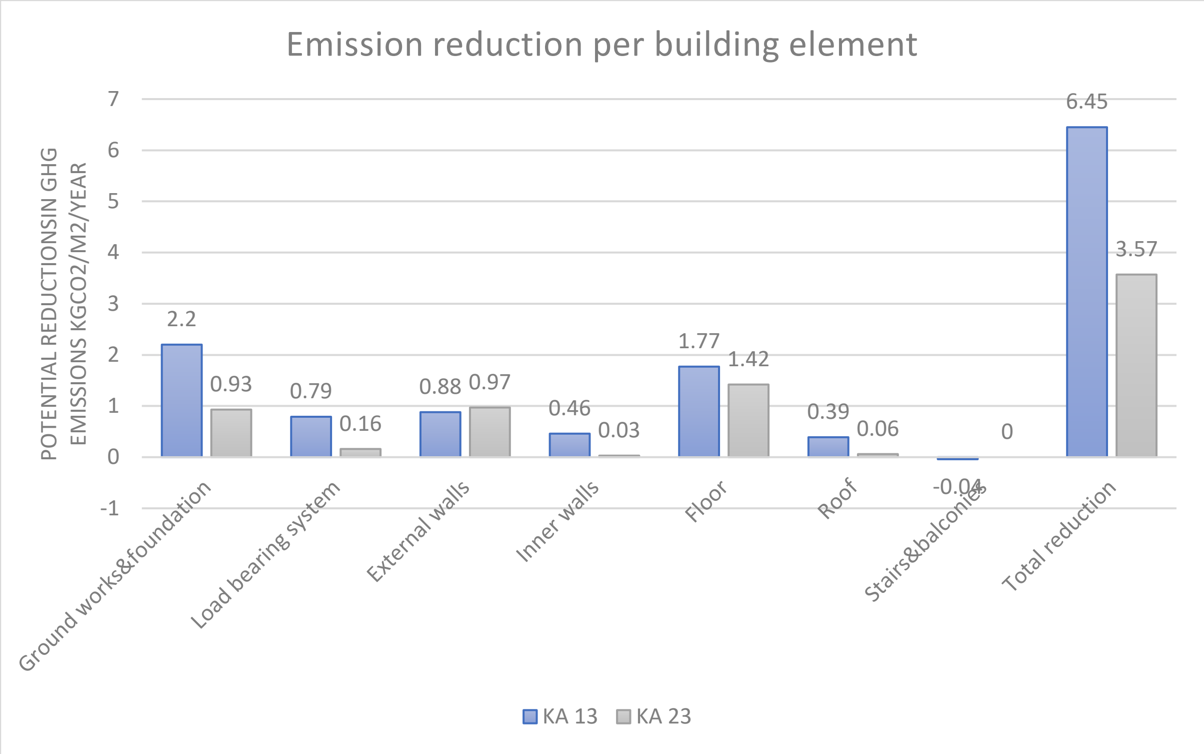


Figure 4.2: Distribution of calculated GHG emission reduction per building part for KA13 and KA23.

According to GHG reports for KA13 and KA23, the project's total greenhouse gas emissions compared with the reference calculation, have been reduced by 40% and 55% for the "as-built" KA13 and KA23 respectively. The greenhouse gas emissions for the KA13 project "as-built" are estimated at 39.38 kg CO2 eq./m2/year, and 822 kg CO2 eq./person/year. In total for the building, this amounts to 159,473 kg CO2 eq./year. While the greenhouse gas emissions for the KA23 project "as-built" are estimated at 34 kg CO2 eq./m2/year, and 420 kg CO2 eq./person/year. In total for the building, this amounts to 295,125 kg CO2 eq./year. Table 4.1 shows the reductions for the different phases for total (material use, stationary energy use for the operation of the building, and passenger and products transport during the operation phase) for the entire building, and the total for the material use only.

Table 4.1: GHG emissions for case studies for the Entire building and Material use for different project phases

Project	Reference building	As-Built	
	Kg CO2eq./m²/year	Kg CO2eq./m²/year	Reduction compared to reference building [%]
KA13 (Total: Material, Energy and Transport)	66.17	39.38	40 %
KA23 (Total: Material, Energy and Transport)	74.43	33.84	55 %
KA13 (Material use)	9.20	2.75	70 %
KA23 (Material use)	4.3	0.73	83 %

Table 4.2: Distribution of GHG emissions for case studies per building part for different project phases and the relevant reductions

Building element	Reference building Kg CO2eq./m²/year		As-Built Kg CO2eq./m²/year		Reduction compared to reference building Kg CO2eq./m²/year	
	KA13	KA23	KA13	KA23	KA13	KA23
Groundworks and foundations	2.6	0,93	0.4	0	2.2	0.93
Load bearing system	0.9	0.21	0.11	0.05	0.79	0.16
External walls	1.4	1.07	0.52	0.1	0.88	0.97
Inner walls	0.8	0.3	0.34	0.27	0.46	0.03
Floors	2.9	1.63	1.13	0.21	1.77	1.42
Roof	0.6	0.11	0.21	0.05	0.39	0.06
Stairs and Balconies	0	0.05	0.04	0.05	-0.04	0
Total	**9.2**	**4.3**	**2.75**	**0.73**	**6.45**	**3.57**

The results show that the total emission reduction from material use for KA13 is 2.88 Kg CO2.eq/m²/year more compared to KA23. While the emission reduction for KA23 (83%) is 13% more compared to KA13 (70%). Although the used area (BRA) for KA23 (8721 m²) is quite larger compared to KA13 (4050 m²). This difference is due to that the reference building for KA23 does not consider the GHG emissions from the retained foundation and load-bearing system as done in KA 13 calculations. Multiconsult AS in their material note rev 02, see Appendix 00, did not consider the retained building components. *"The report also does not include all building components that will remain where they are today in existing buildings, such as. supporting structure, stairs, facade towards street level, etc."* For complete documentation of the KA23 reference building, with emission factors, service life, and solutions, see Appendix 2.

4.1.2 Groundworks and foundations

The calculations show that for the case projects compared to the reference calculation, emission reductions per groundworks and foundations of 85% and 100% are achieved for "as-built" KA13 and KA23 respectively, see figure 4.3. The main reason for the reduction in greenhouse gas emissions is that existing buildings' foundations have been preserved. There is also a high degree of reuse in the extensions which leads to a further reduction in greenhouse gas emissions. As mentioned before, we can notice in the reference foundation of KA23 that only the piles are considered, as shown below in table 4.3.

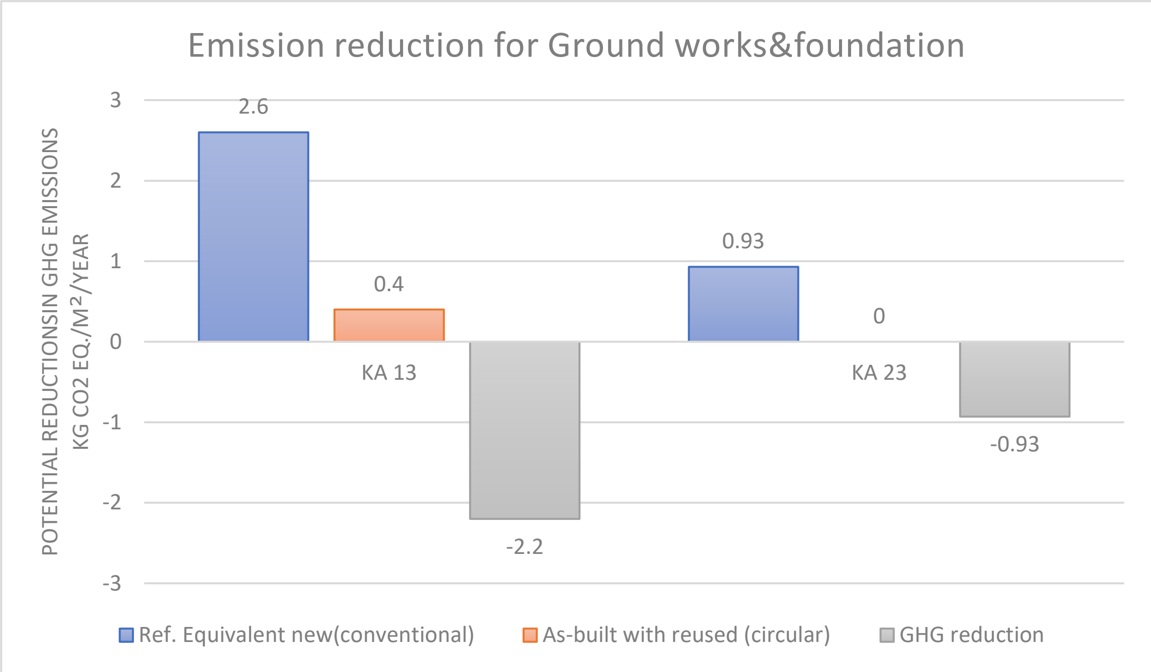


Figure 4.3: Comparative GHG emission and the achieved reduction from foundations for different project phases for KA13 and KA23.

Table 4.3: Distribution of GHG emissions for case studies per Foundations for different project phases and the relevant reduction

<table>
<tr><th rowspan="2">Groundworks and Foundations</th><th rowspan="2">Reference Structure</th><th rowspan="2">As-Built Structure</th><th>Reference Building</th><th colspan="2">As-Built</th></tr>
<tr><th>KgCO2eq./m²/year</th><th>KgCO2eq./m²/year</th><th>Reduction compared to ref. [%]</th></tr>
<tr><td>KA13 (Exist. +Basement)</td><td>Existing foundation</td><td>Reused from existing foundation</td><td rowspan="2">2.6</td><td rowspan="2">0.4</td><td rowspan="2">85%</td></tr>
<tr><td>KA13 Extension</td><td>Pile foundation</td><td>Pile foundation with steel core piles</td></tr>
<tr><td>KA23(Exist. +Extension)</td><td>Steel piles, 20 m depth.*</td><td>Reused from the existing building.</td><td>0.93</td><td>0.00</td><td>100%</td></tr>
</table>

*Existing foundation only the piles are considered

4.1.3 Life cycle impact assessment

In this stage, data is collected from the life cycle inventory is converted into emissions. All calculations are performed using Excel.

In this analysis, it has been chosen to look only at the environmental impact category of global warming potential (GWP) in the form of kg CO2 equivalents. This is considered the most relevant and interesting to consider, in addition to the fact that there is uncertainty and a lack of information about environmental impact beyond CO2 emissions from the reuse processes.

4.1.4 Load-bearing systems

The calculations, in figure 4.4, show that for each project compared to the reference calculation, emission reductions per load-bearing system of 88% and 76% are achieved for "as-built" KA13 and KA23 respectively. The main reason for the reduction in greenhouse gas emissions is that existing buildings' bodies and loadbearing systems have been

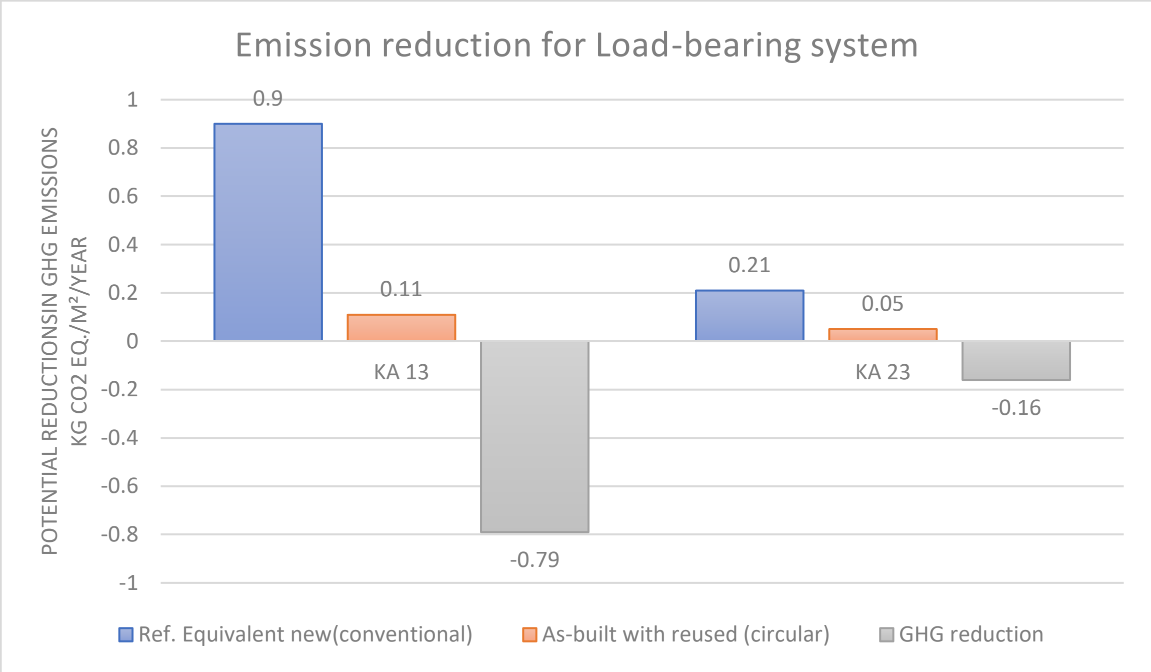


Figure 4.4: Comparative GHG emission reduction from Load-bearing system for different project phases for KA13 and KA23.

preserved. The utilization of reused steel columns and beams in KA13 in the new extension leads to a significant reduction in greenhouse gas emissions. While in KA23 new columns and beams were used in the extensions. Here, we can notice in the reference building s load-bearing system of KA23 that it is a relatively low value, although KA 23 is almost 50% bigger compared to KA13. Description of load-bearing system with associated greenhouse gas emissions for the different building phases, existing building+extension, is shown above in Table 4.4.

Table 4.4: Distribution of GHG emissions for case studies per Load-bearing system for different project phases and the relevant reduction

Load-bearing System	Reference Structure	As-Built Structure	Reference Building	As-Built	
			KgCO2eq./ m²/year	KgCO2eq./ m²/year	Reduction compared to ref. [%]
KA13 (Exist. +Basement)	Existing columns and Beams in concrete and steel	Reused from Existing.The extension on level 9 is made with steel columns and beams	0.9	0.11	88%
KA13 Extension	Steel columns and beams	Steel columns and beams. Existing			

		concrete columns on the 1st floor have been preserved			
KA23 (Exist.+Extension)	Columns and beams are of concrete and steel	Somewhat reused from existing buildings, some new from steel	0.21	0.05	76%

4.1.5 External walls

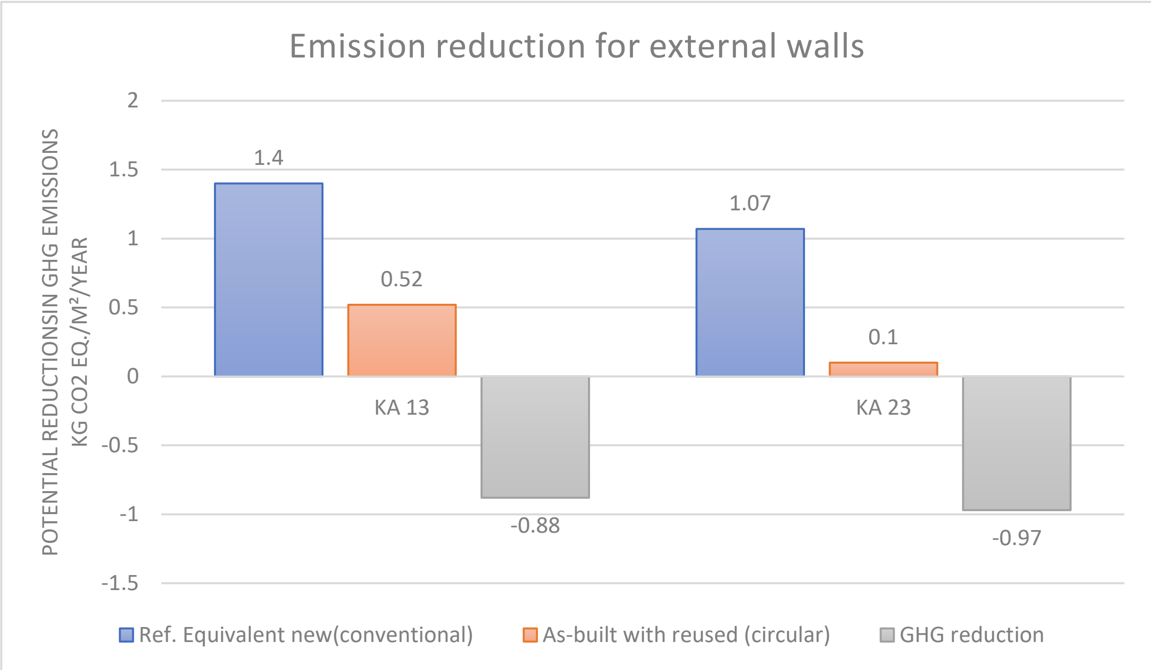


Figure 4.5: Comparative GHG emission and the achieved reduction from External walls for different project phases for KA13 and KA23.

Figure 4.5 shows the calculations for the case projects compared to the reference equivalent per External walls. Reductions of 71% and 90% are achieved for "as-built" KA13 and KA23 respectively. The main reason for the reduction in greenhouse gas emissions is that existing buildings' external walls have been preserved to a good extent especially the reused facade plates in KA13 and the natural stone plates in KA23 which contribute to a remarkable reduction. The same applies to external walls, we can notice in the reference building of KA23 that it is a relatively low value, although KA 23 is almost 50% bigger compared to KA13. This is because of Multiconsult consideration of preserved building parts, that were not included in the calculations as well as the outer wall has a conservation status following the Planning and Building Act.. Description of the external walls with associated greenhouse gas emissions for the different building phases, existing building+extension, is shown in Table 4.5.

Table 4.5: Distribution of GHG emissions for case studies per External walls for different project phases and the relevant reduction

<table>
<tr><th rowspan="2">External walls</th><th rowspan="2">Reference Structure</th><th rowspan="2">As-Built Structure</th><th>Reference Building</th><th colspan="2">As-Built</th></tr>
<tr><th>KgCO2eq./m²/ year</th><th>KgCO2eq./m²/ year</th><th>Reduction compared to ref. [%]</th></tr>
<tr><td>KA13 (Exist. +Basement)</td><td>Concrete walls with cladding and wooden windows with metal cladding</td><td>Existing concrete walls and cladding have been preserved. Wooden windows with aluminum cladding.</td><td rowspan="2">1.4</td><td rowspan="2">0.52</td><td rowspan="2">71%</td></tr>
<tr><td>KA13 Extension</td><td>Standard outer wall with timber frame, insulation, and plasterboards inside.
Typical windows with aluminum cladding. Fasade panels in metal and sement.</td><td>Climate wall with external wind barrier (GU-X), trusses with wooden posts and mineral wool, vapor barrier, and internal plaster.
Windows are largely reused. Wooden windows with aluminum cladding.
Reused facade panels in metal and fiber cement.</td></tr>
<tr><td>KA23 (Exist.+ Extension)</td><td>Exterior walls are insulated timber walls, concrete walls, and LECA walls with natural stone as a facade and plaster and tiles as interior cladding. There are also some glass facades.</td><td>Mainly reused from existing buildings, window glass, some glass facades, and some LECA walls are new.</td><td>1.07</td><td>0.10</td><td>90%</td></tr>
</table>

4.1.6 Internal walls

The calculations show that for each project compared to the reference calculation, emission reductions per the internal walls of 58% and 10% are achieved for "as-built" KA13 and KA23 respectively. In KA13, the main reason for the reduction in greenhouse gas emissions is that the building's floor was planned as open space. This means that there is little need for interior walls, which means that this item deviates most from the reference building. While in KA23, the reduction in greenhouse gas emissions was not so great due to the significant amount of new interior walls in the project. The description of interior walls with associated greenhouse gas emissions for the different building phases for case projects is shown in Table 4.4.

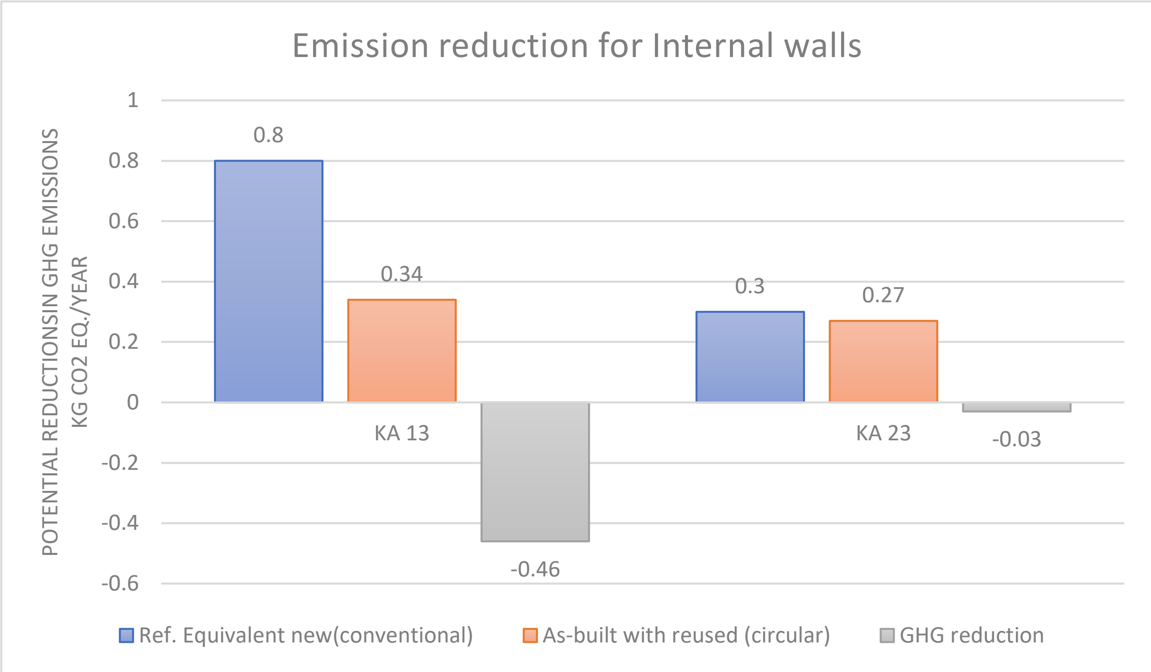


Figure 4.6: Comparative GHG emission and the achieved reduction from Internal walls for different project phases for KA13 and KA23.

Table 4.6: Distribution of GHG emissions for case studies per Internal walls for different project phases and the relevant reduction

Internal walls	Reference Structure	As-Built Structure	Reference Building	As-Built	
			KgCO2eq./m² /year	KgCO2eq./ m²/year	Reduction compared to ref. [%]
KA13 (Exist. +Base ment)	Timber-frame walls, insulation, plasterboards. Wet areas, plaster, and ceramic tiles. CLT walls in offices.	Timber-frame walls, mineral wool, plaster on each side. Steel studs. System glass walls. Ceramic tile with a membrane in the wet room. TEWO system walls in some offices.	0.8	0.34	58%
KA13 Extensi on	Timber-frame walls, insulation, plasterboards. Wet areas; plaster, and ceramic tiles. CLT walls in offices.	A small degree of interior walls Timber-frame wall, mineral wool, plaster on each side. Steel studs. System glass walls. Ceramic tile with a membrane in the wet room. TEWO (CLT) system walls in some offices.			

KA23 (Exist. +Extension)	Interior walls are glass-wool-insulated truss (timber frame) walls made of steel studs with plaster and tiles as cladding. Some drywall has plywood.	New plaster/drywalls, glass fronts, and interior doors. The plaster walls have steel studs and rock wool insulation, and either fiber plaster or standard plaster. Some plaster walls have OSB or plywood. Some new tiles. Otherwise reuse.	0.3	0.27	10%

4.1.7 Flooring

The calculations show that for case projects compared to the reference new equivalent, emission reductions per the flooring of 61% and 87% are achieved for the "as-built" KA13 and KA23 respectively. In KA13, the main reason for the reduction in greenhouse gas emissions is the high degree of preservation of concrete floors as well as the reuse of hollow-core slabs from the donor building, the old government headquarter. While in KA23, the flooring was one of the largest achieved reductions due to the high degree of reuse and preservation of flooring as well as the use of concrete with lower greenhouse gas emissions than the reference values in the extension. The description of flooring with associated greenhouse gas emissions for the different building phases for case projects is shown in Table 4.7.

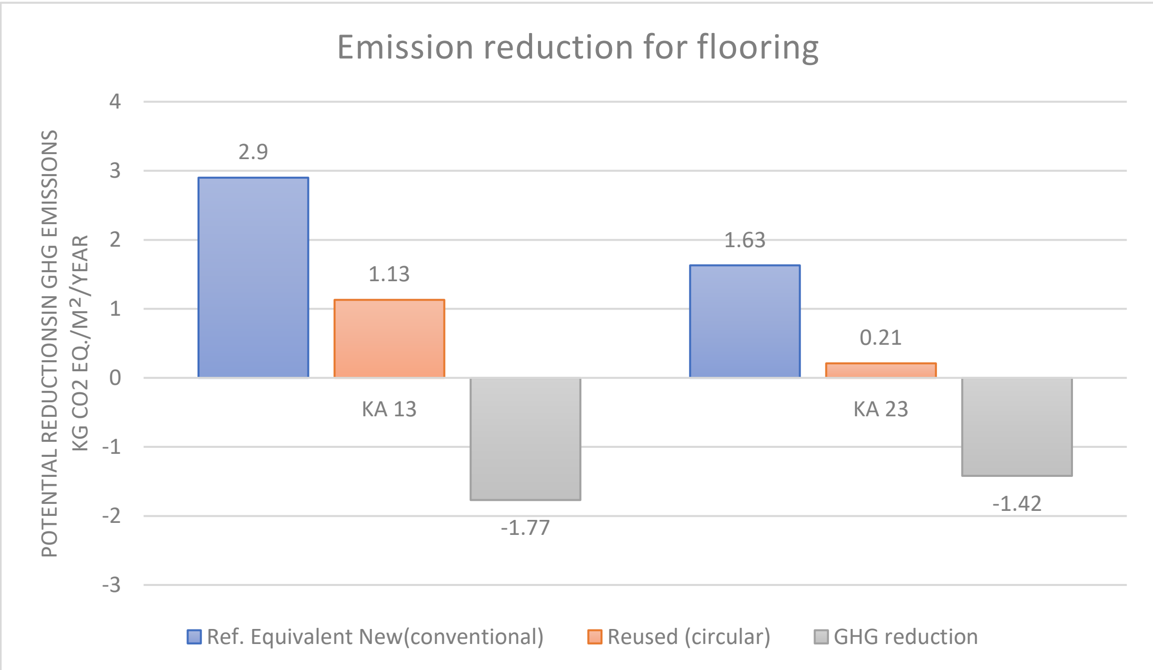


Figure 4.7: Comparative GHG emission and the achieved reduction from Flooring for different project phases for KA13 and KA23.

Table 4.7: Distribution of GHG emissions for case studies per Flooring for different project phases and the relevant reduction

Flooring	Reference Structure	As-Built Structure	Reference Building	As-Built	
			KgCO2eq./m²/year	KgCO2 eq./m² /year	Reduction compared to ref. [%]
KA13 (Exist. +Basement)	Hollow-core slabs in concrete, and screed layer. Carpet tiles in the office area. Ceramic tile with the membrane in the wet room. Ceiling tiles and mineral wool insulation. Acoustic treatment and thermal insulation.	Existing concrete floors are preserved, except in the basement, where there is a new concrete floor against the ground. Screed and rehabilitation of some floors. Carpet tiles in large parts of office areas. Ceramic tile with the membrane in the wet room. Ceiling boards, and mineral wool in the ceiling. Sonaspray in the ceiling for acoustic treatment.	2.9	1.13	61%
KA13 Extension	Hollow-core slabs. Ceiling tiles and mineral wool insulation. Acoustical treatment and thermal insulation.	Hollow-core slabs Reused hollow-core slabs Ceiling tiles, and mineral wool in the ceiling. SonaSpray for acoustic treatment.			
KA23 (Exist. +Extension)	Floors consist of hollow-core slabs and cast-in-place concrete. The floor surface is Kebony, vinyl, carpet, terrazzo tiles, parquet, plaster, and linoleum. The ceiling is wooden wool and plaster.	Mainly reused from existing buildings. New concrete floor in the extension, some ceiling (wood wool) and floor covering (carpet, terrazzo casting, linoleum, parquet, and epoxy) are new.	1.63	0.21	87%

4.1.8 Roof

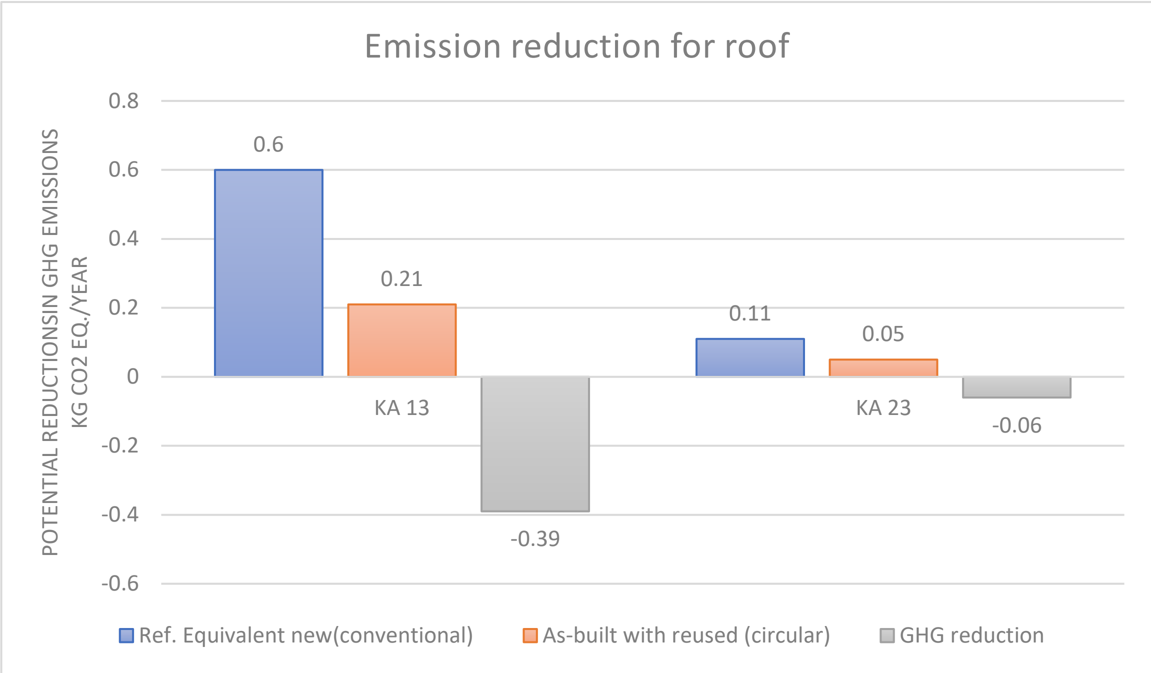


Figure 4.8: Comparative GHG emission and the achieved reduction from the Roofs for different project phases for KA13 and KA23.

Figure 4.8, shows the calculations for the case projects compared to the reference equivalent per outer roof. Reductions of 65% and 55% are achieved for "as-built" KA13 and KA23 respectively. The main reason for the reduction in greenhouse gas emissions is that existing buildings' roofs have been preserved to a good extent. Description of the structure of the external walls with associated greenhouse gas emissions for the different building phases, existing building+extension, is shown in Table 4.8.

Table 4.8: Distribution of GHG emissions for case studies per Roof for different project phases and the relevant reduction

Roof	Reference Structure	As-Built Structure	Reference Building	As-Built	
			$KgCO2eq./m^2/year$	$KgCO2 eq./m^2/year$	Reduction compared to ref. [%]
KA13 (Exist. +Basement)	Compact concrete roof, steel plates, insulation, and bitumen membrane roofing.	Blue-green roof. Sedum roof with insulation. Existing concrete roofs have been preserved. Terrace floors on balconies.	0.6	0.21	65%
KA13 Extension	Compact concrete roof, steel plates, insulation, and bitumen membrane roofing.	Blue-green roof. Sedum roof with insulation. Existing concrete roofs have been preserved.			

KA23 (Exist. +Extension)	The outer roof consists of compact roofs of concrete, glass, steel plates, aluminum, insulation, and bitumen polymer membrane roofing.	Mainly reused from existing buildings. New galvanized steel roof, green roof, and tender royal. Re-insulation of the existing roof and new roof in extension.	0.11	0.05	55%

4.1.9 Stairs & Balconies

The calculations, in figure 4.9, show that for case projects compared to the reference new equivalent, no emission reductions are achieved for "as-built" KA13 and KA23 per stairs and balconies. The existing stairs were excluded from greenhouse gas emissions in KA13. While in KA23 Greenhouse gas emissions have increased somewhat for stairs and balconies, mainly due to the steel stairs under the greenhouse, which in the reference building are modeled as concrete. Thus, the reuse of stairs was barely noticeable. Description of stairs and balconies structure with associated greenhouse gas emissions for the different building phases, existing building+extension, is shown in Table 4.9.

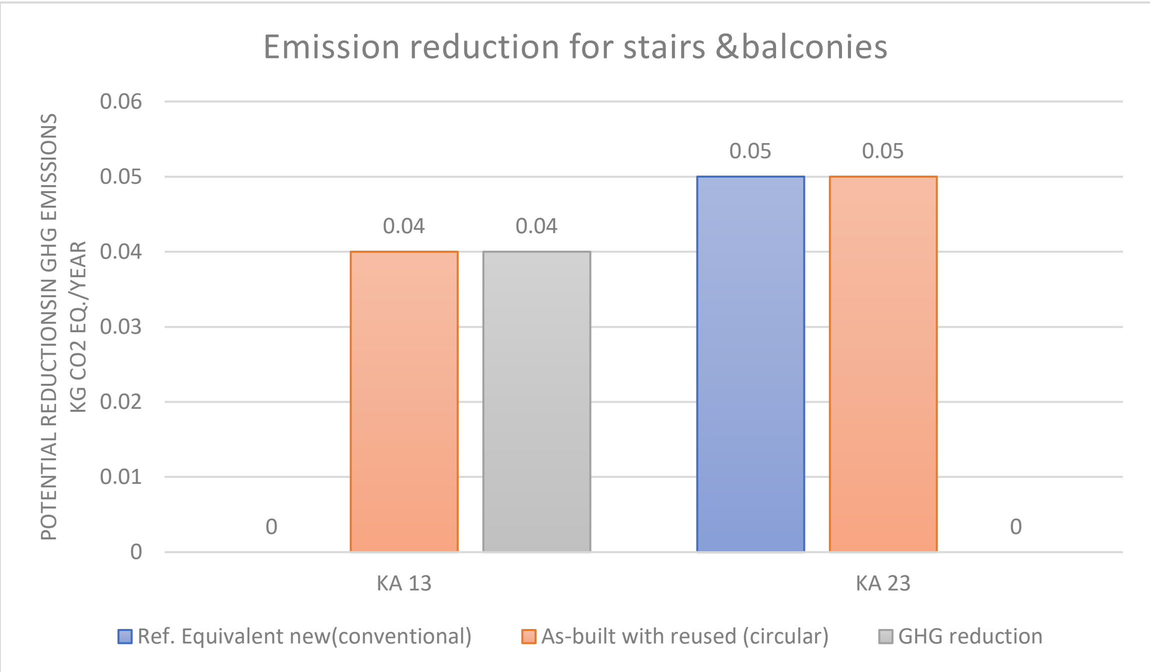


Figure 4.9: Comparative GHG emission and the achieved reduction from the Stairs and Balconies for different project phases for KA13 and KA23.

Table 4.9: Distribution of GHG emissions for case studies per Stairs and Balconies for different project phases and the relevant reduction

Stairs and balconies	Reference Structure	As-Built Structure	Reference Building	As-Built	
			KgCO2eq. /m²/year	KgCO2 eq./m² /year	Reduction compared to ref. [%]
KA13 (Exist. +Basement)	Stairs and balconies are made of concrete and timber.	Concrete ramps and internal stairs in concrete.	0.0	0.04	-4%

		Existing stairs are preserved. Wooden stairs from the 1st floor. To the basement.			
KA13 Extension	Stairs and balconies are made of steel and concrete.	Steel stairs along with the new extension. Concrete stairs up to the backyard.			
KA23 (Exist. +Extension)	Stairs and balconies are made of concrete.	Mainly reused from the existing building, new steel staircase under greenhouse and new steel railing on extension.	0.05	0.05	0%

4.2 Comparative environmental analysis per material/product

The case study projects meet FutureBuilt's criteria for circular buildings by a good margin. As mentioned in section 4.1, the greenhouse gas accounts for case projects showed that the major reductions in greenhouse gas emissions were due to the large preservation of existing building masses; the foundations, load-bearing systems, exterior walls, roofs, and floors have been preserved. This means that the renovated building has very low greenhouse gas emissions compared to the reference building. There is also a high degree of reused materials in the existing buildings and their extensions as well as the use of materials with lower greenhouse gas emissions than the reference values.

In KA13, the existing load-bearing system and external walls are retained, except for the necessary rehabilitation works of new hole-making and reinforcements. About 75 percent of the steel is reused for both the existing building and the new extension, and the supporting structure in steel uses a large amount of reused steel profiles. The achieved reduction from the reuse of steel structure was 2.65 KG CO2eq./m²/year or 83%, see figure 4.11. Besides, reused hollow-core slabs from the government quarter (R4) on three floors have been used in the extension. The reduction achieved from reinforced concrete was 3.92 Kg CO2eq./m²/year or 90%. Also in other parts of the project, there is a lot of reuse such as facade panels, and interior equipment such as radiators, sanitary equipment, ducts and pipes, and office fronts and doors which contribute to further significant reductions, see figure 4.11. Furthermore, there was a close collaboration with the tenant “Spaces” on the reuse of interior surfaces on floors, walls, and ceilings. Spaces were very positive to a large extent of return to original surfaces such as tiled columns. Architecturally, the building's floor plan as an open space means that there is little need for interior walls, which means that gypsum- and plasterboards and relevant steel and wooden-studs system and insulation deviate most from the reference building, see Table 4.11. But it has not only been a goal in the project to reuse building materials. What is newly built in the project has a design and execution that makes it possible with any future reuse. For KA13's complete list of reused elements used in the greenhouse gas calculations, see Appendix 1.

For KA23, The building has many reused building materials and therefore deviates significantly from the reference building. Floors, exterior walls, and groundworks and foundations are the building parts that lead to the highest greenhouse gas emissions for adapted reference buildings. So, Concrete, steel, and glass walls are the most contributing materials. Relevant greenhouse emission reductions per Kg CO2eq./m²/year were 1.8, 0.84, and 0.38 respectively, see Table 4.11. Measures implemented to reduce greenhouse gas emissions from materials include the use of recycled materials instead of new ones, carpets made of recycled material (plastic bottles and an old fishing nets), low-carbon concrete of class B, fiber gypsum instead of standard gypsum, and steel columns with lower greenhouse gas emissions from production than the reference. In addition, there is a high focus on reusability and flexible solutions as well as proper disposal. For the extension of the building at an early project stage, some measures have been assessed and rejected including building the extension in solid wood (CLT), extension in reused materials, and extension with a plastered façade instead of a glass façade. These had to be rejected due to the tight schedule of the project. See Appendix 2 for a complete overview of material quantities.

Figure 4.10 shows the distribution of the calculated greenhouse gas emission per material/product for different project phases for KA13 and KA23 in the carried out comparative life cycle analysis. The following material/product categories are analyzed:

- Steel structure
- Glass
- Reinforced concrete
- Doors and windows
- Gypsum- and plasterboards
- Wood
- Brick, stone, and ceramic
- Façade cladding
- Insulation
- Ceiling panels
- Floor covering

Table 4.10: Distribution of GHG emissions for case studies per building material/product for different project phases and the relevant reductions

Material/ product category	Reference building Kg CO2eq./m²/year		As-Built Kg CO2eq./m²/year		Reduction compared to ref. building Kg CO2eq./m²/year	
	KA13	KA23	KA13	KA23	KA13	KA23
Steel structure	3.20	0.97	0.55	0.13	2.65 (83%)	0.84 (87%)
Glass	0.17	0.44	0.14	0.06	0.03 (18%)	0.38 (87%)
Reinforced concrete	4.35	1.83	0.43	0.03	3.92 (90%)	1.8 (98%)
Doors&windows	0.25	0.37	0.19	0.21	0.06 (24%)	0.16 (44%)
Gypsum boards and studs	0.06	0.08	0.04	0.02	0.02 (34%)	0.06 (75%)
Wood	0.03	0.04	0.03	0.03	0.00 (0%)	0.01 (2.5%)
Facade cladding	0.22	0.02	0.08	0.00	0.14 (64%)	0.02 (100%)

Brick, Stone & ceramics	0.17	0.09	0.12	0.04	0.05 (30%)	0.05 (56%)
Insulation	0.14	0.04	0.13	0.02	0.01 (7%)	0.02 (50%)
Ceiling panels	0.06	0.01	0.02	0.00	0.04 (67%)	0.01 (100%)
Floor covering	0.84	0.25	0.73	0.09	0.11 (14%)	0.16 (64%)

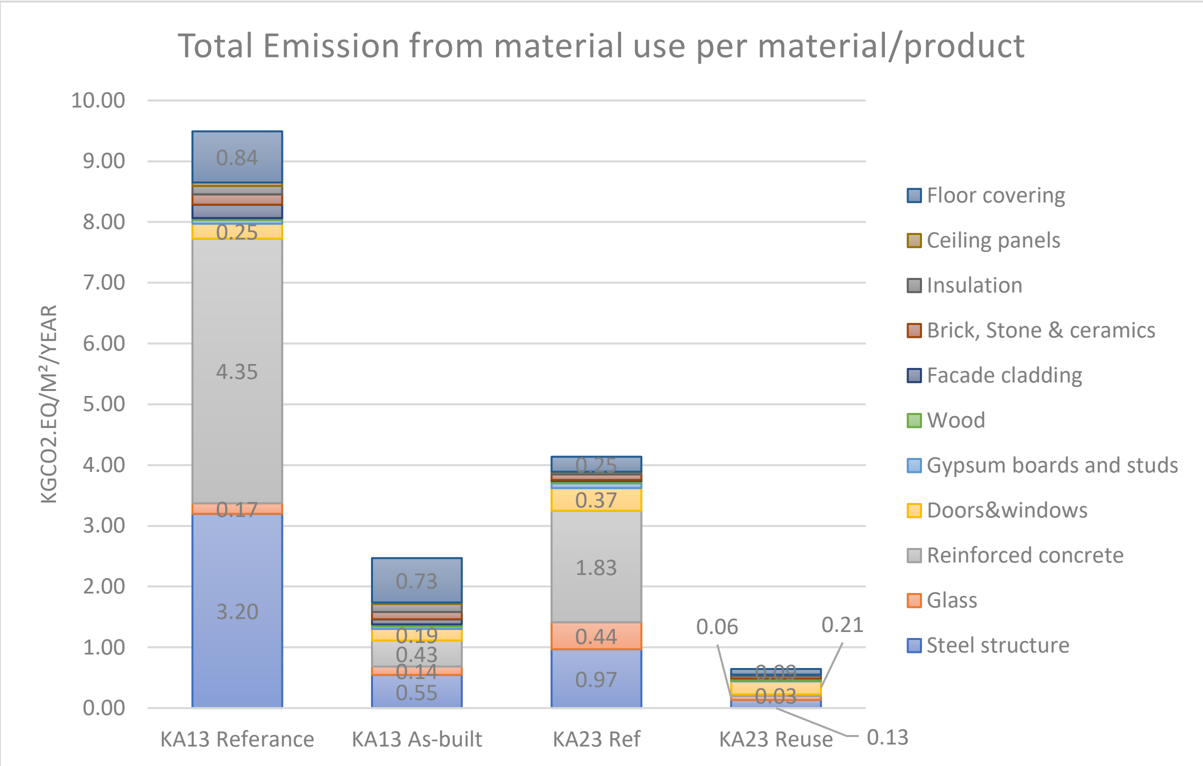


Figure 4.10: Distribution of greenhouse gas emissions per material/product for different project phases for KA13 and KA23.

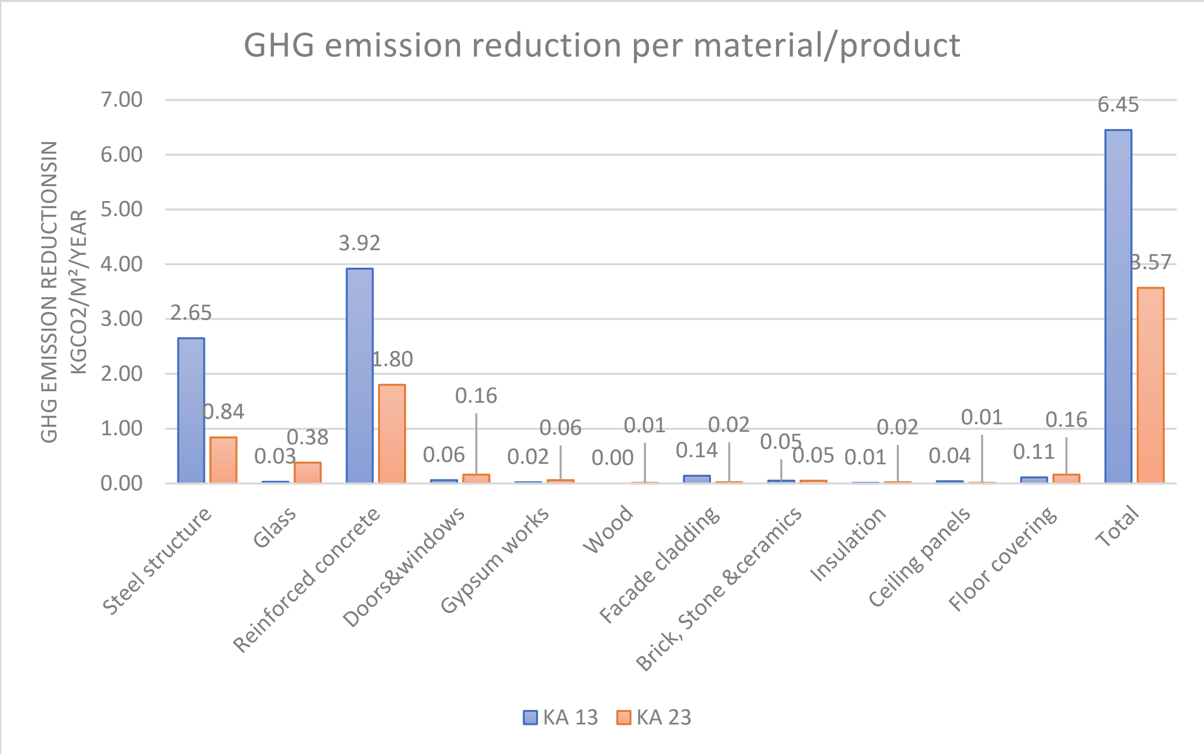


Figure 4.11: Distribution of calculated GHG emission reductions per material/product for KA13 and KA23.

Figure 4.11 shows the distribution of total calculated greenhouse gas emission reductions for KA13 and KA23 projects with the utilization of the reuse products compared with corresponding new alternatives. It has not been decided to address other environmental impacts than greenhouse gas emissions, in the form of Kg $CO2.eq/m^2/year$. The results apply to phases A1-A3, which constitute processes from the start of the life cycle and the replacement phase.

Afterward, a more specific comparative life cycle analysis has been carried out for selected reusable materials used in KA13 and KA23. The selection of such categories was based on the largest reduction contribution of greenhouse gas emissions from one side, and the corresponding comparability from the other side. The basic greenhous gas calculations for materials/products for different project phases for KA13 and KA23 can be found under Appendix 1 amd Appendix 2 respectively.

A brief presentation of the analyzed materials and products is summarized in Table 4.11. In Table 4.12, the savings per unit for phases A1-A3 and B4 are presented for the different material categories.

Table 4.11: Overview of relevant material categories analyzed from KA13 and KA23.

Material/ Product	Project	Analysis unit	Total amount reused	Obtained from	Reuse process	Reuse type	Year
Steel structure profiles of beams and columns	KA13	Kg steel rolled and hollow profiles	36,142 kg	Eastern Norway area	Cutting, sandblasting and priming	External	unknown
	KA23	Kg steel rolled and hollow profiles	10,950 kg	Procured new	---	----	2020
Concrete Hollow-core slabs	KA13	Ton hollow-core slabs of thickness 265 mm + 80 mm screed	21 pcs. (Type HD265), 160 m² (on 3 floors), 96 tons	Government quarter, R4	Cutting, testing Approx. 1985	External	About1985
	KA23	Ton hollow-core slabs of thickness 265 mm	About 236 tons	Reused from Existing building	testing	Local/internal	1951
Brick	KA13	m³ Firewall in brick (Of this, approx. 20,000 bricks used in KA13, approx. 10,000 stones that were not used.	34 m³ (About 20,000 pcs) About 40 ton	Øst Riv, from the following projects: a.Strømsveien 185 b.Bergensgata 41-43 c.Tine Kalbakken, Bedriftsveien 7 d.Darres gate 2	Cleaning of mortar and testing	External	a. before 1955 b. 1913, 1947 and 1981 c. before 1955 d. 1930s/ 1940s
	KA23	m³ internal walls brick	196.6 m³ (324.34 ton)	Reused in an external project due to lack of documentation	Taken out, cleaned, and sold	Sold	1951
Windows & Doors	KA13	m² 3-layer windows of size 1,588x1488 mm and 1,588x2,188 mm m² Doors: different sizes	87 m² of windows(30 pcs) 153 m² of doors (81 pcs; 17 existing + 64 from donor build.)	Windows: Turbinveien 15, and Nordregate 20-22. Doors: Refstad skole(UBF), DEG8 (Braathen eiendom) and St. Olavs plass 5 (Entra)	No process for windows and cleaning and painting for doors	External for windows and 17 were internal, and 64 pcs external	2014
	KA23	m² different sizes	About 1660 m²(740 m²	Reused from Existing building	No process	Local	1951, 2004

			doors and 920 m² windows)		for windows and cleaning and painting for doors		
Façade cladding	KA13	m² finished cladding	695 m² 401 pcs Cembrit, 1151 pcs and 313 +3381 Metal plates, Steni.	- Cembrit: St. Olav hospital/ Finn.no. - Metal plates: Oppsalhjemmet (OBY)/Rehub -Steni: Rehabilitation of housing project in Alfred Trønsdalsvei 9, Trondheim and Surplus stock	Cutting and varnishing	Surplus and external	1970s, 2009, 2020
	KA23	m² Natural quartzite stone (solvågstein) and stoneware glazed tiles	1916.5 m²of cladding; 1244.8 m ² Natural stone quartzite slate, 12 mm.And 672 m² of stoneware tiles glazed, 10 mm	Reused from Existing building	Cleaning and re-polish	Local	1951

Table 4.12: Reductions in Kg CO_2.eq/unit for the analyzed material categories in phases A1-A3+B4

Material Category	Reused material/ Product	Unit	Emission per unit equivalent new (Reference) Kg CO2eq./unit		Emission per unit with Reuse (As-Built) Kg CO2eq./unit		Reduction compared to ref. building [Kg CO2.eq/unit]		Reduction compared to ref. building [%]	
			KA13	KA23	KA13	KA23	KA13	KA23	KA13	KA23
Steel structure (Steel profiles of beams and columns)	Steel profile, L, U, and I profile	kg	2.08	2.08	0.04	2.08	2.04	0.00	98%	0%
	Steel profile, hollow profile	kg	3.62	3.62	0.08	2.47	3.54	1.15	97.8%	31.8%

Concrete Hollow-core slabs	Hollow-core slabs	m²	85.36	85.36	9.4	0.00	75.96	85.36	89%	100%
		m³	160.48	160.48	17.68	0.00	142.8	160.48	89%	100%
		ton	124.9	124.9	13.9	0.00	111	124.9	89%	100%
Brick	Brick stone	m³	390	-	78	-	312	-	80%	80%*
Windows & Doors	3-layer, 2 fags windows	m²	80.22	69.76	7.22	7.22	73	62.54	78%	89.7%
	Interior doors	m²	66.80	66.80**	9.50	9.50	57.3	60.26	85.8%	85.8%
Façade cladding	Cement, metal, and fiber cladding plates	m²	50.73	-	1.58	-	49.15	-	97%	-
	Natural quartzite stone	m²	6.56	-	-	0.00	-	6.56	-	100%
	stoneware glazed tiles	m³	87.21	-	-	0.00	-	87.21	-	100%

* 324.34 tons of brick was sold to another project and the reduction compared to new would be 80%

** The door factor to KA13 is estimated here due to different types of the reused doors in KA23 (climate -, interior wooden-, multifunctional steel- and glazed doors)

There are large savings to be made by reusing the materials and products in the process and replacement phases. To get a more comprehensive impression of the consequences of the material choices throughout the life cycle, the forthcoming subchapters will provide a more thorough review of each material category, including possible scenarios for replacement.

4.2.1 Steel/structural profiles of columns and beams

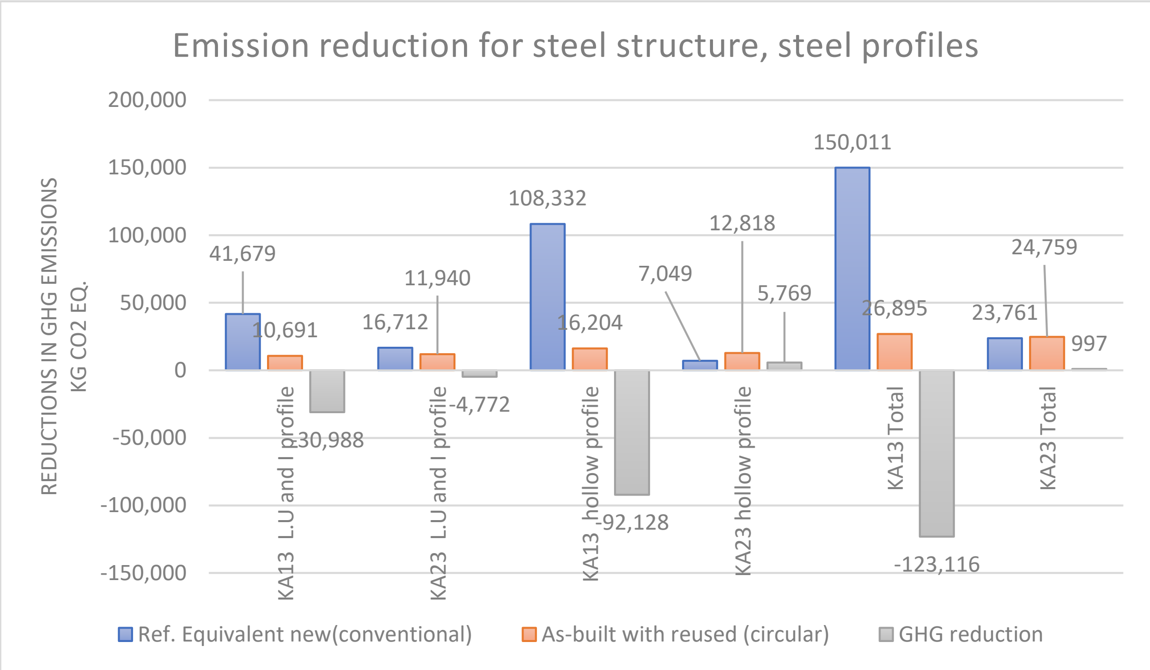


Figure 4.12: Comparative GHG emission and the achieved reduction from structural steel profiles for different project phases for KA13 and KA23.

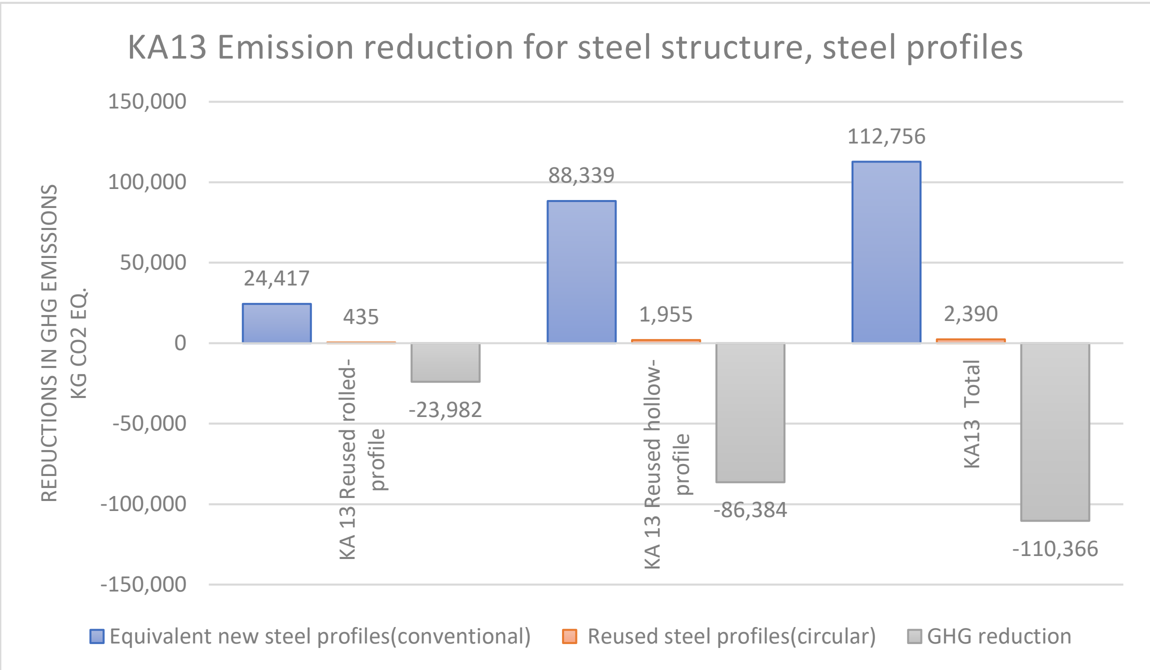


Figure 4.13: Comparative GHG emissions for steel profiles to columns and beams, phase A1-A3, KA 13.

The total results from material use, Figure 4.11, showed that building with reused steel, in general, provides relatively large savings in greenhouse gas emissions due to an energy-intensive production process for new steel. For the structural steel profiles, in KA13, there are large amounts of steel reused in the project, see Figures 4.12 that show the reduction provided with the use of reused steel profiles, while figure 4.13 show only the contribution of the reused steel profiles in KA13. In KA23 no reductions were achieved, due to the new steel profiles being used.

The reused hollow profiles contribute to approx. 86 tons CO2 saving compared to the new alternative, while L, U, and I profiles contribute to 24 tons CO2 saving compared to the use of the new equivalent. Per kilogram of steel, the savings are 2.04 and 3.54 Kg CO2 equivalents, for the rolled and hollow profiles respectively, which is a reduction of approx. 98% compared with the use of new steel with a recycling rate of 13%. Figure 4.13 shows how the emissions are distributed for different phases.

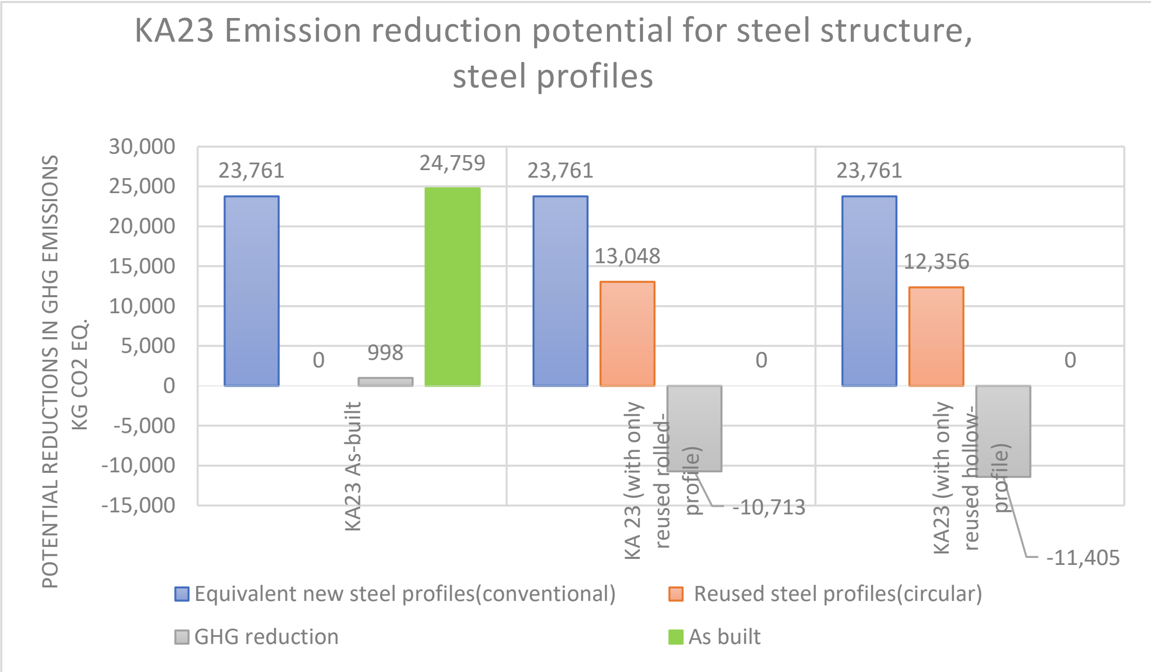


Figure 4.14: Greenhouse gas emissions reduction scenarios for steel columns and beams, phase A1-A3, KA 23.

In KA13, a total of 75% of all steel in the project has been reused, and the reuse of steel profiles contributed to a significant emission reduction, see figure 4.13. It is suggested in KA23 two reuse scenarios. The first scenario is to substitute the L.U and I profiles with reused alternatives to achieve an emission reduction of about 50% compared to the As-built scenario. While the other scenario is to retain the As-built of L, U, and I profiles and only substitute the hollow profiles with reused alternatives, which will also contribute to approx. 50% CO2 saving. Substitution scenarios are illustrated in figure 4.14. Steel has an estimated service life of 100 years, so there will be no need for replacement throughout the building's service life. In this case, only phases A1-A3 have been analyzed. The processes that make the greatest contribution to the greenhouse gas accounts during reuse are the processing of the steel, which includes, among other things, cutting, sandblasting, and priming of all surfaces. For further details about greenhouse gas contributions, see Appendix 2.

4.2.2 Concrete/Hollow-core slabs

In KA13, an approx. of 96 tons reused hollow-core slabs have only been used on three of the eight floors in the extension, but provide a saving of 10.6 tons of CO2 eq. In KA23, 236 tons of hollow-core slabs have been retained and 32.8 tons of CO2 eq. is achieved.

Per ton of hollow-core slabs, this means a 111 kg and 124.9 kg CO2 equivalent reduction in greenhouse gas emissions for KA13 and KA23 respectively, which corresponds to an 89% reduction relative to corresponding new hollow-core slabs for KA13 and 100% for KA23. See Figure 4.15 for a presentation of the results.

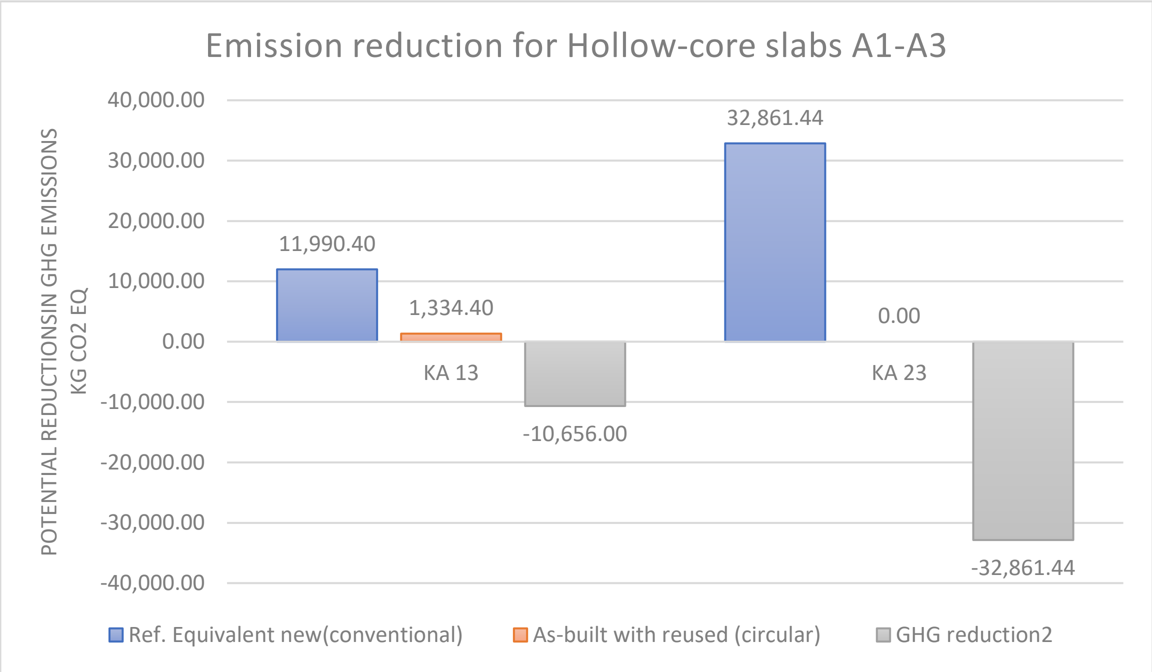


Figure 4.15: Comparative greenhouse gas emissions from the hollow-core slabs, phase A1-A3

In line with the steel elements, in KA13, the hollow-core slabs are part of the load-bearing structure of the extension, and will not be replaced during the life of the building. The slabs have been inspected by the project team and tested by SINTEF, and it is assumed that the service life is equal to the service life of the building even though they are 35 years old. Thus, only phases A1-A3 are included. According to the reuse report, most of the contributions for the used slabs are associated with transport, up to 90% of total emissions, both to the construction site (A4) and intermediate storage (A1-A3). This is because the slabs are heavy, which gives a high emission intensity in transport. It still takes a lot for the reuse of the hollow-core slabs to pay off. They can be transported a full 890 km before the emissions are equivalent to the new alternative, with the assumptions in this analysis. Disassembly and machining cause minimal emissions. In addition, the used elements were very expensive compared to new perforated tires. The casting also resulted in reduced floor heights compared to the original plan.

Figure 4.16: Reuse of the hole-slabs from the government quarter (R4) (Elverum, 2020)

It was chosen to keep the original screed on the reused hole decks to take care of as much of the concrete as possible. On the floors where new perforated decks have been used, there is no need for screed, as the floor area in the extension is relatively small (53 m²). Thus, greenhouse gas emissions for screed are not included for the corresponding new perforated tires. Larger projects will often be included, which will lead to even greater savings when reused. Thus, the reuse of existing hollow-core concrete slabs in a building can create a new structure for the other and a significant CO_2 saving.

4.2.3 Brick

In KA13, an approx. of 34 m³ (40 tons) of reused brick stone has been used as a solution for a firewall facing the neighboring building (Faculty of Law). The reuse of brick provides a saving of 10.6 tons of CO_2 eq. In KA23, about 196.6 (324.34 tons) of brick have been dismantled from the interior walls and decided not to be used in the project due to the lack of documentation and have been sold to another project. In this study, we have assumed a scenario of this amount of brick being reused to compare with KA13. In that case, a reduction of 61.3 tons of CO_2 eq. will be achieved. Per m³ of brick, this means a 312 kg CO_2eq. reduction in greenhouse gas emissions for KA13 and KA23. which corresponds to an 80% reduction relative to the corresponding new brick. See Figure 4.15 for a presentation of the results.

The rehabilitation and demolition contractor (Øst-Riv) has acquired bricks from various buildings that they have demolished. Everything is transported from the buildings that have been demolished to Øst-Riv's storage site at Slemmestad, where cleaning and preparation have taken place.

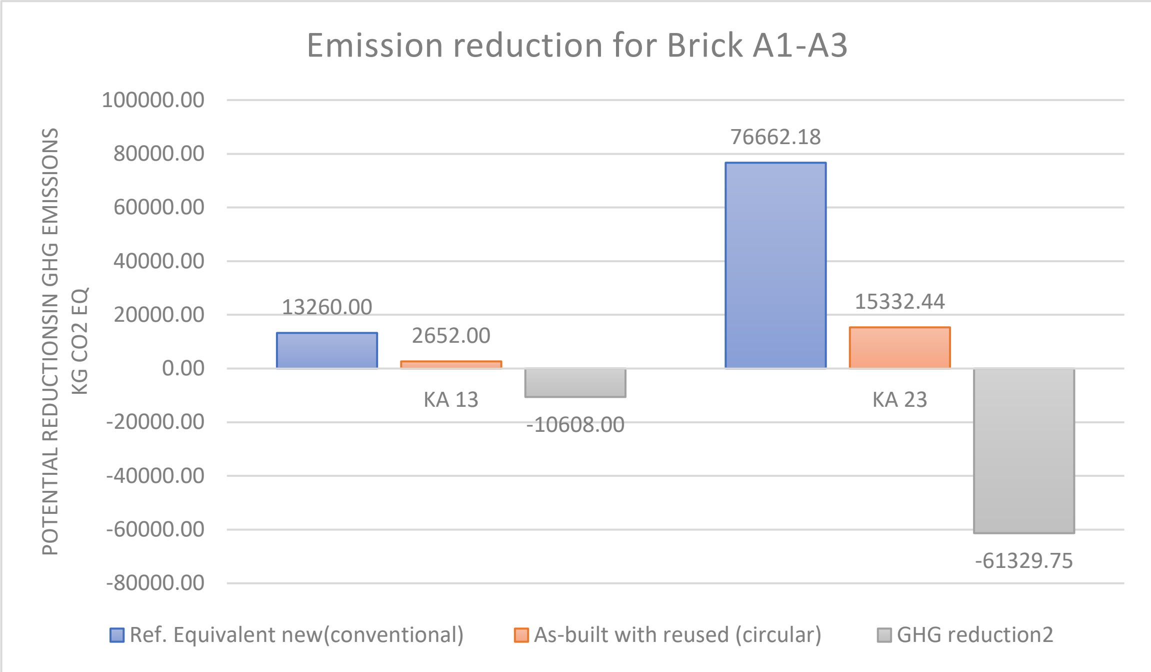


Figure 4.18: Comparative greenhouse gas emissions from brick stones, phase A1-A3

The number of bricks made available in the project was originally estimated at 30,000 stones. The amount was reduced due to that the total weight became too high for the foundations. In addition to the weight of the brick wall, there were also additional loads from the used hollow-core slabs. LECA has therefore been used as a firewall on three floors. The result is that it was approx. 10,000 stones that were not used.

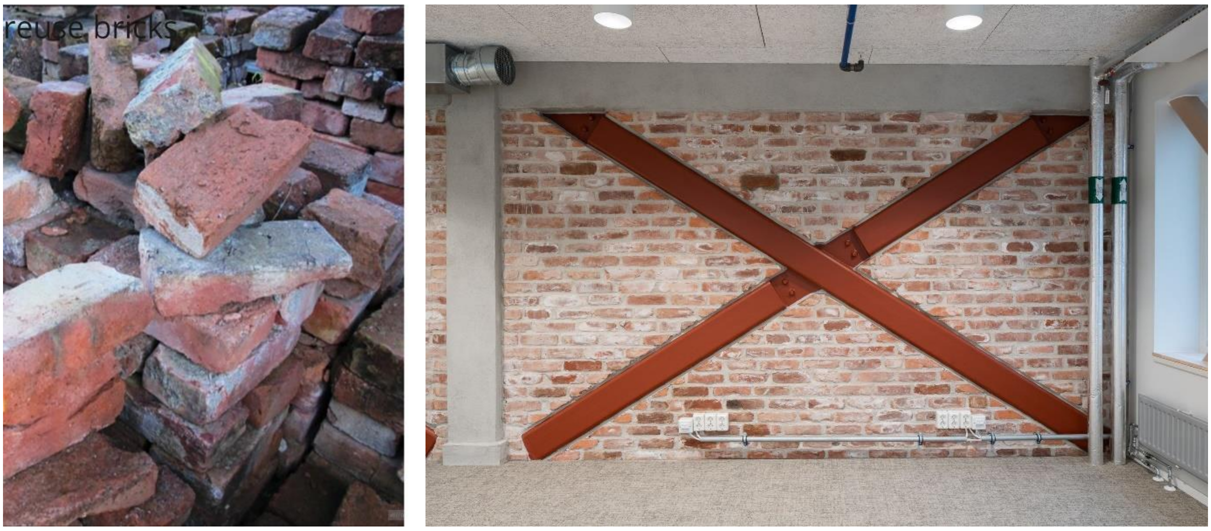


Figure 4.17: The reuse of brick in KA 13 and finished firewall (Elverum, 2020)

4.2.4 Windows and doors

In KA13, the existing windows from the 1980s had poor woodwork and a lack of sealing around the frame, and could not be fixed, so they can not be kept. The fabrication of the new alternatives, based on the existing insulating glass, was said by several suppliers to be at a higher price compared to the new ones. Besides, due to the need for daylight, it was not relevant to decide on the window size, and it is naturally very challenging to find used windows that fit exactly into existing facade openings. All windows in the existing building are therefore new (Nordby et al., 2020). The existing windows in KA23 were mostly retained. The windows were relatively in a good condition as well as the existing protection status of the façade.

The reused windows, in KA13, were incorrectly designed in a housing project in Kværnerbyen (Turbinveien 15) and were acquired by Resirqel, see figure 4.18. An approx. of 87 m^2 (30 pcs) have been used on the fifth to the eighth floors in the extension, and provide a saving of 6.4 tons of CO2 eq. compared with a new alternative in phases A1-A3 and B4. This amounts to 73 kg CO2 eq. per m^2 of the window, which corresponds to a 78% reduction relative to corresponding new windows. The windows are from 2014, and it is assumed that the remaining life of the windows is just over 30 years. Thus, it will be necessary to replace them during the life of the building. While in KA23, an approx. of 921 m^2 of windows have been retained from the existing building and about 64 tons of CO2 eq. of greenhouse gas reduction is achieved. Per m^2 of a window, this means a 62.54 kg CO2 equivalent reduction in greenhouse gas emissions, which corresponds to a 90% reduction relative to corresponding new windows.

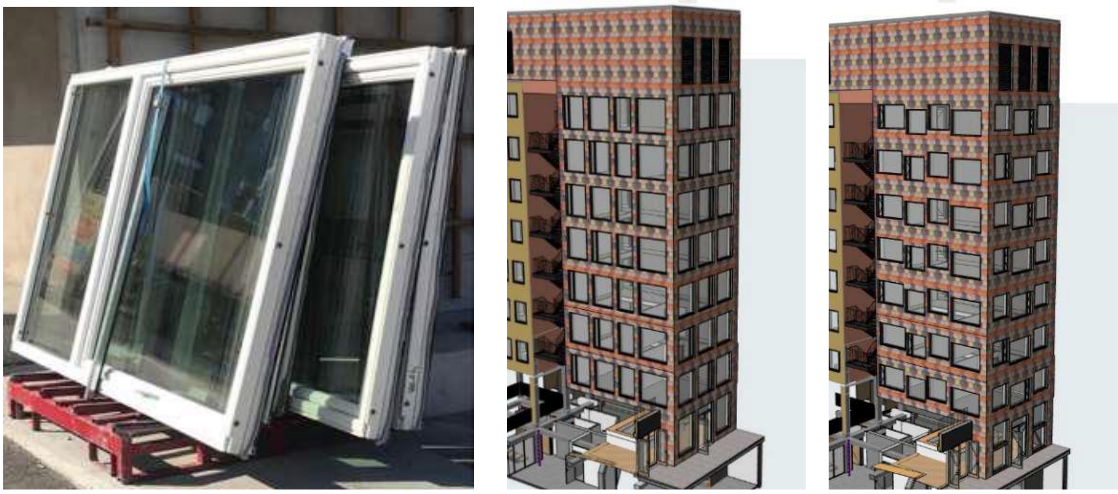


Figure 4.18: Windows dismantled from a housing project in Kværnerbyen Photo: Resirqel, Facade extension, designed with 1) New windows, 2) Used windows. Illustrations: MAD architects (Nordby et al., 2019)

Figure 4.19: The reuse of existing windows in KA23 (Arcasa Architects, 2022)

For the reused doors in KA13, 17 pcs. of the existing doors in KA13 have been retained in their original position, shown in figure 4.18. The rest of the doors have been moved to new walls. Some of the reused doors are only green soap washed, while others have been cleaned and surface treated. Besides, 64 doors were reused from other donor buildings. A total of about 153 m² of doors were reused in the KA 13 project and about 740 m² in KA23. The reuse of the doors has provided a saving of 7.2 and 19.3 tons of CO_2 eq. compared to the use of new alternatives for KA13 and KA23 respectively. This amounts to 57.3 kg CO_2 eq. and 60.26 kg CO_2eq. per m² of the door, respectively for KA13 and KA23, which corresponds to about 86% reduction relative to corresponding new doors. The total greenhouse gas emission from doors and windows is shown in figure 4.20.

Figure 4.20: The reuse of the existing doors in KA 13 (Nordby et al. 2019)

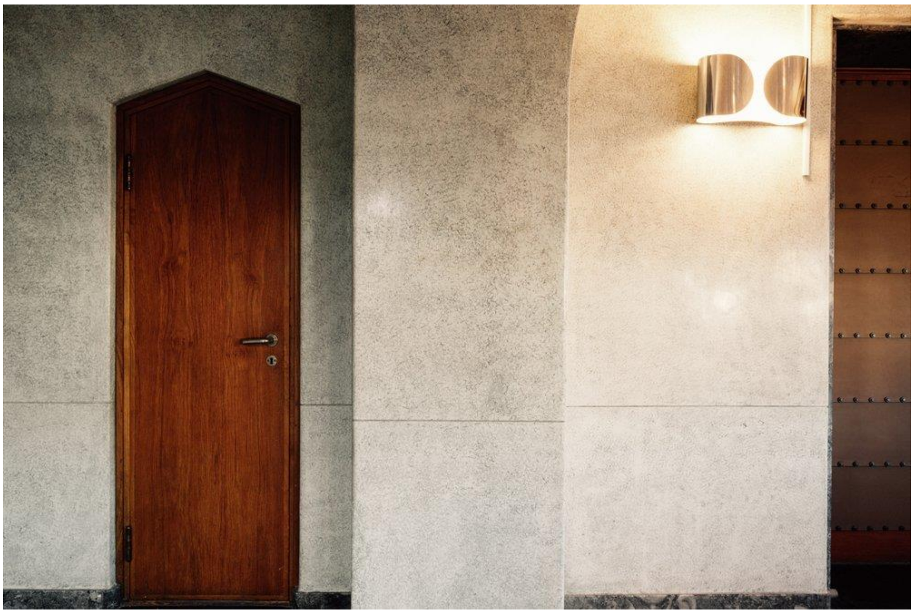


Figure 4.21: The reuse of the existing doors in KA23 (Arcasa Architects, 2022)

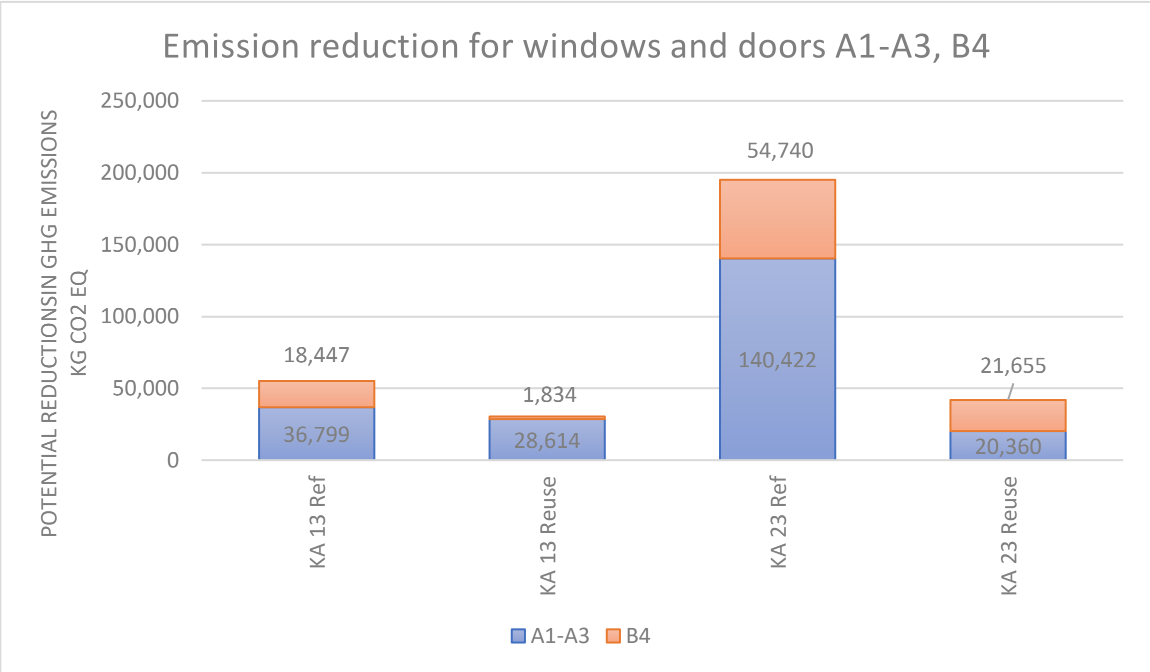


Figure 4.22: Comparative total greenhouse gas emissions from windows and doors, phases A1-A3 and B4

4.2.5 Fasade cladding

The chosen solution in KA13 for facade cladding in the extension provides a 97% cut in greenhouse gas emissions from phases A1-A3 compared with a new solution. This amounts to as much as 33.2 tons of CO2 eq, as shown below in Figure 4.21.

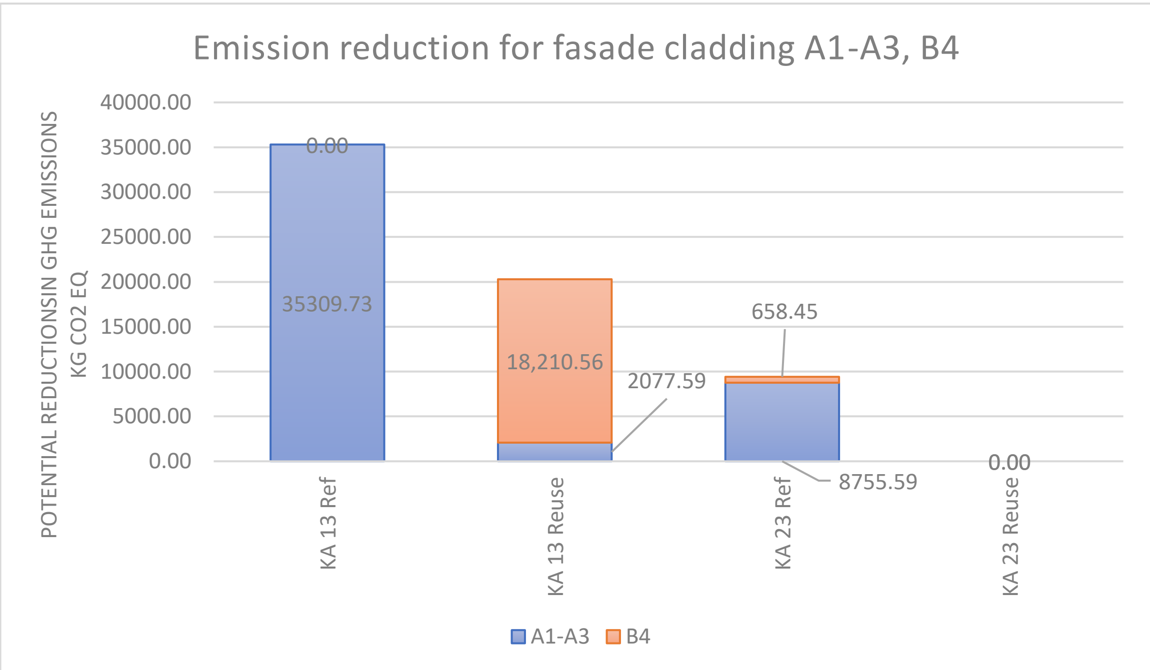


Figure 4.23: Comparative greenhouse gas emissions from façade cladding, phases A1-A3 and B4 for KA13 and KA23.

The façade consists of many different types of façade plates (metal, fiber cement, and stone composite) of different years, see figure 4.22. Approximately 53% of the boards are surplus materials from the Steni factory's warehouse, which allegedly would have been sent for waste treatment if they had not been used here. It is not described as reuse but has been chosen to be taken into account as it opens up some interesting issues in the life cycle assessments. For example, whether the production of the materials is to be taken into account or not, and it has been decided in this analysis not to include emissions from the production.

In KA23, about 1916.5 m² of stone cladding was retained from the existing building. An approx. of 1244.8 m² of natural stone quartzite slate, with a thickness of 12 mm, and 672 m² of stoneware tiles glazed, of 10 mm thickness were preserved. Figure 4.21 shows the comparative greenhouse gas emission from façade cladding for phases A1-A3 and B4.

Thus, the reused façade cladding in KA23 provided 6.56 kgCO2 eq. per m² cladding of natural stone and 87.21 kgCO2 eq. per m³ cladding of other stoneware glazed tiles. Figure 4.23 shows the retained natural stone quartzite (solvågstein) in the KA23 project.

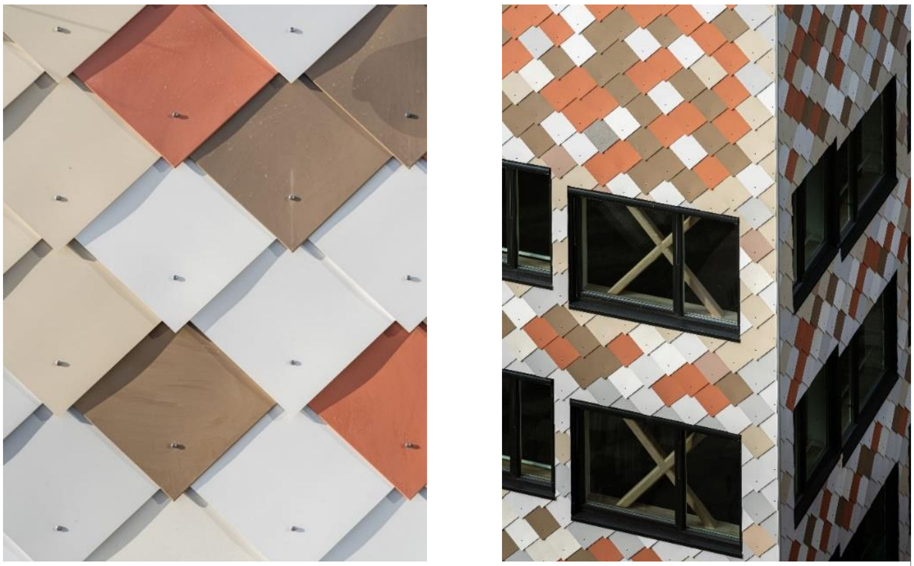


Figure 4.24: The reused façade cladding in KA 13 (Mad Architects, 2019)

Figure 4.25: The natural quartzite stone façade cladding in KA23 (https://www.ka23.no)

4.3 Comparative reuse calculation

4.3.1 Background for calculating quantities of reusable materials

In FutureBuilt's set of criteria for circular buildings, v. 2.0, 16.03.2020, Futurebuilt has defined the following quantitative requirements for reuse and reusability.

The project will facilitate resource utilization at the highest possible level according to the definition of the circular building in FutureBuilt's criteria for circular buildings, that at least 50% of existing building structures are taken care of and that at least 10% of the components supplied to the building must be reused (Nordby,2020).

In total, at least 50% of the components in the project (calculated by weight, e.g. ground and foundation) must be reused or reusable according to sections 2.3 and 2.4. (Nordby,2020). It is up to the project to define the approach and distribution of different measures.

In new buildings, at least 20% of the components (calculated by weight, e.g. ground and foundation) must be reused, and reuse must be carried out for min. 10 component types, defined as different building parts according to building component table, 2-digit level. See building component table below.

For the rehabilitation projects at least 50 percent of the existing building structures must be preserved (calculated by weight, ex ground and foundation). Maintaining of existing

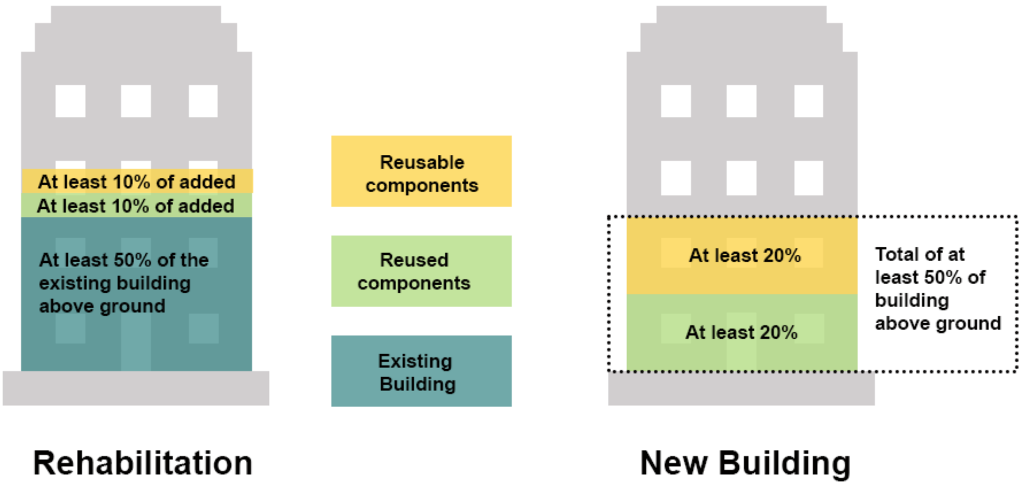


Figure 4.26: Illustration of quantitative requirements for reuse and reusability for circular buildings, FutureBuilt's criteria for circular buildings, v2.0 - 16.03.2020. (Nordby, 2020)

building structures counts as reuse in the reuse accounts. In addition, at least 10% of the components supplied to the building must be reused, and reuse must be carried out for min. 5 component types, defined as different building parts according to the building part table, 2-digit level. The reuse documentation requirements, it is mainly focused on the following points:

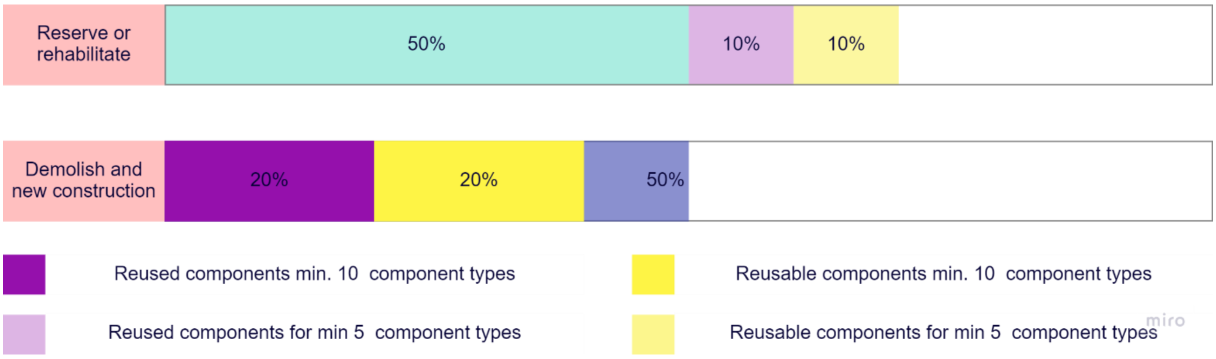
- Reused quantity and type of components are stated as weight and percentage of the building's weight

• Numbering is based, as far as possible, on the specific weight of components, including technical installations.

• Procedures for quality assurance and material documentation should be described. Thus, quality and properties must be documented in such a way that the building parts satisfy the requirements in TEK and the Building Products Directive (DOK).

Table 4.13: Building components with required reuse and reusability elements

	Required reused from acquisition	Reused from acquisition/procurement (Imported)	Required reusable	Reusable
Building part, 2-digit level	5 Pcs.	22 Bearing system 23 Exterior wall 24 Interior wall 25 Floor/Covers 26 Exterior roof 27 Fixed inventories 28 Stairs and balconies 31 Sanitary 32 Heat 33 Firefighting 36 Air treatment 37 Air cooling 43 Distribution	5 Pcs.	22 Bearing system 23 Exterior wall 24 Interior wall 25 Floor/Covers 26 Exterior roof 28 Stairs and balconies



Here, the project's estimate of the achieved weight percentage for resp. local reuse, external reuse (reuse from procurement), and reusability.

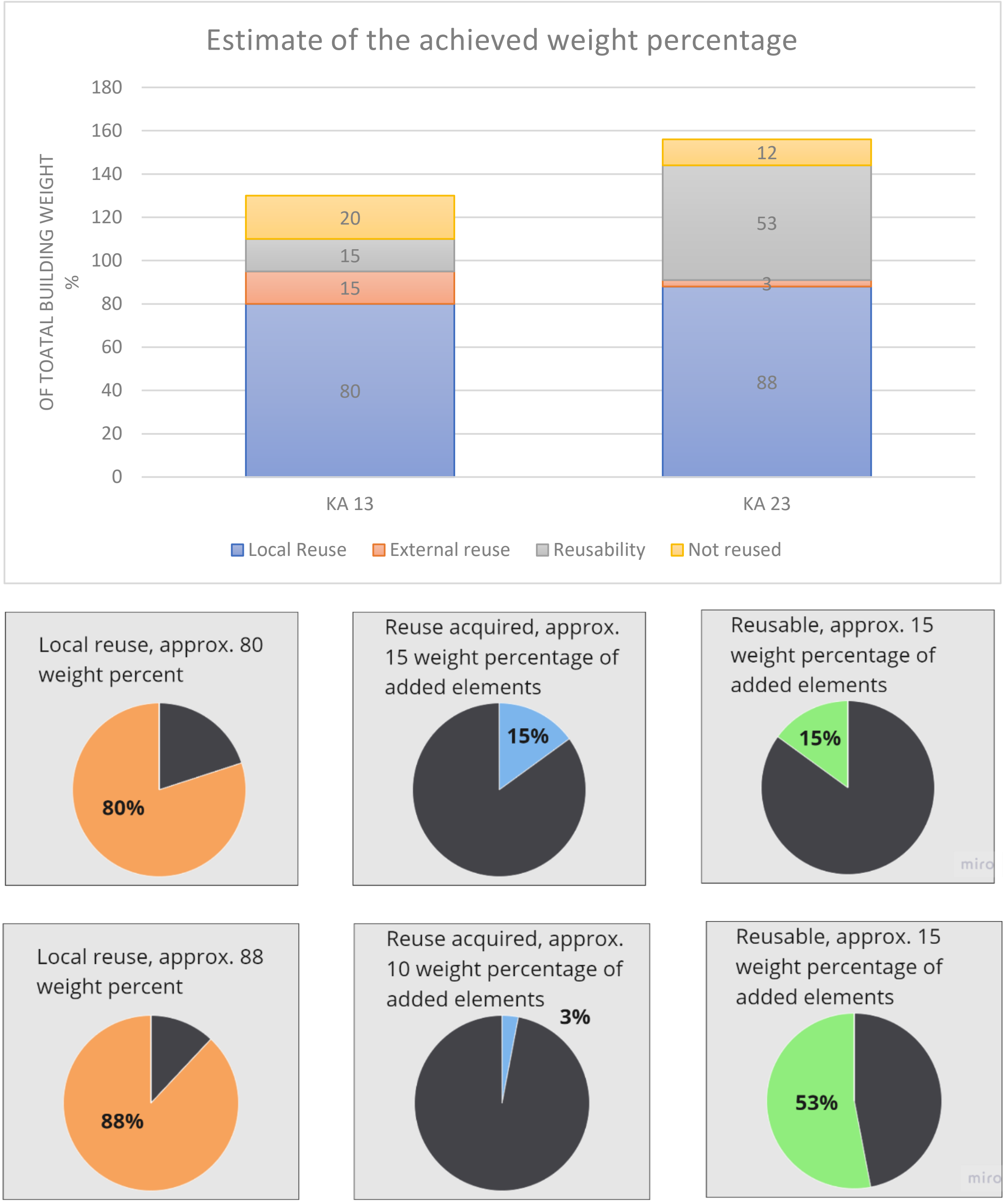


Figure 4.27: Building component with required reuse and reusability elements

4.3.2 Local reuse

Since case studies are rehabilitation projects where it was chosen to keep as many of the existing constructions as possible, the requirements for local reuse (50%) were met without problems.

Local reuse amounts to approx. 80% and 88% of the total weight of the projects KA13 and KA23, respectively as shown in figure 00. In general, the total weight of the building is estimated on as built calculations; on a combination of loads used in connection with dimensioning of foundations and support system and calculations based on quantities and dead weights for different materials. While in new building, other methods for calculating weight could be more appropriate, for example, some calculator programs may calculate weight in addition to cost.

4.3.3 External reuse and reusability

For the External reuse procured from "donor buildings", the proportion was approx. 15% by weight of elements added to the project for KA13. The figure is similar for the proportion of reusability of added materials. While it was only 3% for KA23.

In KA13, there was some overlap between what is reused and what is reusable. For example, the brick in the brick wall was built of reused stone, and bricked with lime mortar that makes the wall reusable in the next round. As a percentage by weight of the building's total weight, the share of reuse and reusability is approx. 3%. The building elements that make up most of the reused and reusable elements are the steel structures, the brick wall and the facade cladding.

<u>Large Material weight = large greenhouse gas savings</u>

There is a large correlation between greenhouse gas reductions and weight, so that a reuse calculation based on weight facilitates that reuse results in large greenhouse gas savings. Elements such as sanitary equipment, technical equipments and surface materials such as paints and floor coverings give little account in the reuse calculation. However, these are elements with a high replacement rate with a potential for reuse rather than a use-and-throw mentality.

To motivate re-use also for elements that give a smaller payout percentage, Futurebuilt has specified a minimum number of components according to the building component table (2-digit level) which must be reused from acquisition and reusable, respectively. The requirement is set at 5 and 10 for rehabilitation and new construction, respectively.

4.3.4 Disposal/Sale(not reused)

As mentioned in chapter 3.5.1.1. Disposal of used building materials has not been relevant for many items. Most of what was usable in existing buildings were reused in KA13. The total amount of the disposed of materials was 20% of the total weight and 12%, respectively for Kristian august gate 13 and Kristian august gate 23.

5 Discussion

In this chapter, the research questions will be discussed based on the theory and results from the comparative environmental system analysis. Overall, the idea is that this will build towards an answer to the problem.

5.1 What building materials are possible and suitable to reuse?

Through the study, several materials have been identified that can be considered well suited for reuse (Kilvær et al., 2019; Sørnes et al., 2014, etc.). Practical examples of reuse have also been highlighted, including through the case projects KA13 and KA23. Theoretically, the possibilities for reuse are many. Creative ways of thinking about What the reused material can be used for can also help to increase the potential for more material groups.

On the other hand, it has been proven that today there are many challenges related to the market situation, the legal framework, and how the existing buildings are grouped. This entails limitations on what is possible and legal to implement. Nor is it taken for granted that what can be implemented can necessarily be considered appropriate reuse. This raises questions about which materials and solutions are worth investing in with a view to their wider reuse. What does it take for materials and products to be suitable for reuse?.

5.1.1 What is the difference between possible and suitable reuse?

What is possible to reuse can be said to be related to what is legal, technical, and practically feasible. Here, among other things, the legal framework comes into play. As described in the theory, current regulations, standards, and procedures are not designed to facilitate reuse, which in many cases creates challenges and uncertainty (Kilvær et al., 2019, Asplan Viak, 2018, 2020). The possibilities for dismantling, transporting, and storing the materials without causing damage are further among the criteria for reuse to be practically feasible. What is possible to achieve will also depend on which materials are possible to obtain at the right time on the market, what needs they must meet, and what financial framework the project in question has.

What can be considered suitable reuse, is a more comprehensive assessment. Whether something is suitable must be determined based on whom it concerns and their goals and ambitions. If the goal is, for example, to test the possibilities for large-scale reuse in projects, such as in KA13 and KA23, perhaps all reuse is suitable because it will be able to provide valuable experience for later. On the other hand, if we want to focus on reuse for the least possible environmental impact in a project, it may be better to prioritize the products that have been shown to have the greatest impact on the project's greenhouse gas accounts.

Nielsen et al. (2014) have prepared a complex evaluation method for assessing the reuse potential of materials and products, as shown in Figure 2.9. The material's service life, maintenance needs, and quality are included as part of this method and may be central in assessing what can be considered appropriate. The consequences of service life and replacement intervals are made visible in the environmental system analysis. It is required to ensure a reasonable life of the building under TEK17 §9-2, which gives reason to choose durable materials. Admittedly, there is little experience with lifetime assessments for used materials and products. It is advantageous with materials of good durability, and for which one can easily assess the remaining service life. Thus, it is not worth investing in materials that have too short remaining life.

From a larger perspective, what is suitable to reuse may be related to which materials and products it is possible to achieve effective and more industrialized solutions for some time to come. As described in the chapter on today's re-use practices, the current reuse market and practices are little defined and constantly changing. Among other things, SINTEF is only in the initial phase with their research project REBUS (REBUS, 2020), which will investigate which materials can be assessed to create more industrialized solutions for testing, redocumentation, etc. An entire infrastructure must be in place to be reused on a larger scale, especially if the reusable materials are to be used in functions that affect building technical properties. What is suitable today may thus be something completely different in the future if processes are put more into the system.

Furthermore, the concept of sustainability will be central in assessing what is appropriate to invest in. As described in the theory, sustainability is not only about environmental impact, but also about economic and social aspects (UN-SDGs, 2019). It is difficult to achieve anything beyond pilot projects as long as it is not related to the concept of sustainability but also financially.

As the reuse market is today, it is not a given that reuse is a profitable practice and appropriate for achieving project success criteria; it is time-consuming, uncertain and in the worst-case expensive (Kilvær et al., 2020; Asplan Viak, 2018, 2020, Sunde et al., 2020). Ibeholt et al. (2020) claim that reuse is not very profitable for the developer. The theory has shown that there is currently a lack of financial incentives for players to invest in reuse (Asplan Viak, 2018, Selvig et al., 2020; Ibenholt et al., 2020).

As previously pointed out, it is conceivable that both what is considered possible and appropriate reuse may change in the years to come. Chapter 2.6 sets out several assumptions for an upscaling of the re-use market, with possible incentives for increased re-use. All such factors will play an important role in what is possible and suitable. For example, the EU has started work where they are considering making changes to DOK, which may make it easier to legally use construction products where, for example, there is a lack of documentation. With the EU's investment in the circular economy and Norway's obligations to the EU, it is also conceivable that the economic framework conditions for re-use may change (DiBK, 2017).

5.1.2 What materials are considerable and worth investing in today's market?

The discussion of what is possible and suitable reuse indicates that it is not clear which materials and products are considerable and worth investing in for reuse. Special consideration must be given to practical feasibility, environmental impact, and economic effects. Kilvær et al. (2019) highlighted six categories in particular in their report ”Forsvarlig ombruk” or ”Proper reuse” in English, which is considered to be particularly suitable in today's market. This applies to load-bearing steel, hollow-core slabs in concrete, brick, windows/glass, wood, and materials without documentation requirements. Refer to table 2.2. All of these categories have been tested for reuse in our case studies, but only selected ones have been analyzed. Leland (2008) also mentions technical installations, such as ventilation ducts, etc., as a good option. In KA13, the cooling beams are an example of this being tested. Which products may seem to be related to the concept of sustainability and may be suitable for reuse on a larger scale?

Steel and concrete are examples of heavy materials, of which large volumes according to the waste statistics, are energy-intensive to produce, and have a long service life. According to FutureBuilt's criteria for circular buildings, which operate with requirements for percentages of weight with reused or reusable materials in projects, as discussed in chapter 4.3.1, these materials will also be very favorable for projects to reuse (Nordby,2020; Nordby et al., 2021). Thus, both materials are considerable and worth focusing on and investing in. The load-bearing steel is well suited for disassembly, even though steel connections are not necessarily designed for disassembly. According to Kilvær et al. (2019), it is also possible to achieve external reuse of steel with current regulations. On the other hand, it seems that reusing the steel in KA13 entails increased costs. This involves relatively large sums in the project, but can still be argued to be defensible with concern to the environmental aspect (Nordby et al., 2021). The steel sections used in the KA23 were new-produced and two reuse scenarios were proposed related to avoiding energy-intensive production and excavation of raw materials. In each case, further savings in greenhouse gas emissions can be achieved. Below is a summary of the learning points for the reuse of steel according to Nordby et al. (2021) in the reuse experience report:

- Access to used steel is a primary challenge today. It is required to find the right dimensions. By upscaling the used market for steel, this can be solved.
- Communication with designers regarding access to different profiles and flexibility in the design is considered crucial for the project's success.
- Reuse requires careful disassembly and handling, which requires more time during demolition
- The test procedures developed in the project, with a limited number of destructive tests, significantly reduce the costs associated with testing.
- There is already a standard that can be used for recertification of used steel: NS-EN 1090-2. This applies only to a few building materials!
- Bolting of the steel elements instead of welding may require greater height and thus come into conflict with floor height and light entry.

When it comes to hollow-core slabs in concrete, the slabs in KA23 were only reserved, for local or in-place reuse. Whereas KA13 is an example of how it is possible to get external reuse. Without reliable figures on what the cost picture looks like here, it is not for granted to take a position on whether it is worth investing in. From an economical and practical perspective, it won't be a realistic alternative due to the costs and complicated dismantling. On the other hand, the alternative solution is often a type of down-cycling, where concrete is crushed and used in landfills. Then the value of the resource is considerably reduced concerning what is possible with reuse. Thus, in practice, It is recommended to leave the load-bearing system of existing concrete buildings standing, as in KA13 and KA23, and hope that a jacking system that creates more distance between the floor decks will be able to have a good effect. Thus, learning points for the reuse of hollow-core slabs are as followed:

- Disassembly requires careful planning to maintain the stability of the "donor building" during disassembly and to ensure safe release and hoisting of the elements.
- Space must be set aside for intermediate storage to be able to process and prepare the hollow-core slabs for installation.
- Procedures for quality assurance and documentation for the reuse of constructive elements must be prepared in close collaboration with designers, contractors, and

suppliers in the project, in addition to relevant external material experts and industry associations.

Glass, for example in windows, is energy-intensive to produce, and can potentially provide good savings (Kilvær et al., 2019). As seen in the analysis of KA13, the need for replacement and the impact on the building's energy efficiency can reduce the environmental effects in connection with the reuse of windows. According to Kilvær et al. (2019), there have previously been few examples of reuse of windows in exterior construction without relatively extensive processing, which probably comes from precisely this impact on the heat loss in the building. As shown in the theory, the requirements for energy efficiency in buildings have become increasingly stringent. The older the windows, the greater the probability that the U-value is low compared to new products. Windows, on the other hand, are examples of products that can be easily dismantled, and there are great financial benefits from reuse. Here, the discussion on whether it is worth investing in will involve whether the re-use products can be regarded as perfect alternatives to new ones. Below is a summary of the learning points for the reuse of windows according to Nordby et al. (2021) in the reuse experience report.

- It is difficult to find used windows with dimensions that exactly match existing window openings in a rehab project. Reuse of windows in a new building is easier to implement.
- Windows of older date can be challenging to reuse, both due to. requirements for U-value and due to environmental toxins used in the period approx. 1965-1989.
- Windows of more recent age can be found in newer buildings that are being rebuilt or demolished, or from incorrect deliveries.
- Reusing windows can be both environmentally and cost-saving. Four factors will form the basis for assessment;
  1. U-value and energy calculations
  2. Daylight requirements
  3. Environmental impacts during production
  4. Possible health/environmentally hazardous content in older windows

A balancing of these partly conflicting factors will determine whether the reuse of windows is possible or undesirable in a new building.

Furthermore, products without documentation requirements are highlighted as a category of low-hanging fruit for reuse (Kilvær et al., 2019; Asplan Viak, 2018). The documentation requirements are avoided if the products do not affect the technical qualities of the building, as the products are not considered then as building materials. It simplifies the processes considerably, as we avoid possible testing and re-documentation. Fixtures and fittings, such as carpet tiles, ceramic tiles, furniture and modular walls (without special sound requirements), and landscape architectural stones and surfaces can be cited as examples here (Kilvær et al., 2019). There are great values in these elements and this type of reuse has been the main focus of Loopfront's survey so far. On one hand, This raises the possibility of creative thinking" outside the box". Aesthetics and quality of the products, on the other hand, will affect which products are worth investing in.

To gain a lasting foothold in the construction industry, it has been shown that reusable materials must be competitive in several areas. For current practice, the conclusion may be that it is most appropriate to invest in certain, larger material groups with the potential to create industrialized processes. Examples of this can be steel, materials without documentation requirements, and bricks. The last-mentioned (latter) has been shown to provide environmental savings and is well suited to several previous projects. On the other hand, there is now an urgent need to reduce resource consumption and greenhouse gas emissions (Bakshi, 2019; UNEP, 2019). This opens up the argument that certain materials should be given priority even though it is not currently profitable, but which may change in the future. This may, for example, apply to the reuse of hollow-core slabs in concrete. At the same time, it must be assessed against solutions for material recycling. For example, it should be considered whether in some cases it is more appropriate with material recycling solutions for concrete rather than reuse.

5.2 What environmental effects does the reuse of selected reusable materials and products have compared to the use of new solutions?

Among the most important driving forces for increasing the degree of reuse in the construction industry are the environmental effects it could have. Reuse reduces the need for extraction of virgin resources and the production of new products. In theory, it has been pointed out that several studies have concluded that reuse provides greenhouse gas savings in projects, but there is still a need for examples that show what is worth investing in reused products and how the service life of the products plays a significant role. The environmental system analysis of the case studies can provide answers to what savings in CO2 emissions the projects have achieved, but to what extent the results can be generalized and which scenarios are most likely to occur is uncertain.

5.2.1 Discussion of results from the environmental system analysis

The comparative environmental system analysis per building element has shown that the reuse of the analyzed material and products on the building parts level largely results in large savings in greenhouse gas emissions compared with new alternatives. The calculations showed that emission reductions from the material use of 70% or (6.45 kgCO2eq./m²/year) are achieved and 83% or (3.57 kgCO2eq./m²/year) for KA13 and KA23 respectively.

The main reason for these reductions is that the existing buildings' mass and load-bearing systems have been preserved to a large extent. Besides a high degree of reuse in the extensions, leads to further CO2 saving, as well as the use of materials with lower greenhouse gas emissions than the reference values. The largest reductions are achieved for groundworks and foundations, load-bearing systems, exterior walls, roofs, and floors. For these building parts, there is a high degree of reuse in both of the projects. For interior walls, the reduction in greenhouse gas emissions in KA23 is not so great due to the significant amount of new interior walls in the project. While in KA13 the reuse of interior partition walls was considered difficult due to sound requirements, formats, and poor quality supply of existing partitions. Within this type of building component, there is a lot of use and waste of bad products. So it was considered to use CLT solid timber walls (TEWO Flex[19]), which are more environmentally friendly and can be dismantled and reused. Also, the used studs in wood or steel contributed to further CO2 savings. In KA23, GHG emissions have increased somewhat for stairs and balconies, mainly due to the use of steel stairs under the greenhouse. While in KA13 the existing concrete and wooden stairs are preserved. However, steel stairs along with the new extension and concrete stairs up to the backyard were used which also contributed to increased GHG emissions. As an overall

[19] Tewo Flex is a standardized system based on a sandwich construction of pre-insulated CLT panels.It is a sustainable wall system consists of reusable elements of solid wood and mineral wool insulation, and contains no environmental toxins. https://tewo.no/flex-2

result of analysis per building element, the rehabilitation of the existing buildings has very low greenhouse gas emissions compared to the reference building.

The comparative environmental system analysis per material/product has shown that the reuse of the analyzed material categories largely results in large savings in greenhouse gas emissions compared with new alternatives. The savings in phases A1-A3 and B4 depend on the amounts of materials that are reused, how much processing and service life for replacement is required, and how energy-intensive the production process is for the new material. This has also been pointed out by Anne Nordby (2019) and Aslan Viak (2018, 2020). Nußholz, Rasmussen, and Milios (2019) emphasize that it is not a given that reuse provides greenhouse gas savings in these phases. Based on this study, it still seems that it takes quite a bit for it not to pay off, as the savings from these phases are between 78% and 98% per unit for all of the investigated materials and products.

Steel is an example of the materials that give by far the largest savings among the analyzed material categories in total, if we exclude the preserved concrete structure, based on the KA13 project experience, see figure 4.11, which coincides well with the theory (Kilvær et al., 2019; Myhre, Widenoja and Kilvær, 2018, Nordby; 2009). Per kilogram of reused steel in, a comparative contribution of 0.04 kg CO2eq. for the steel structure with (L, U, and I) profile and 0.08 for the hollow profile. Thus, an average of 0.07 kg CO2 eq. Kilvær et al. (2019) states for comparison 0.24 kg CO2 eq. The difference here may be that shipping and assembly are not included because it is assumed to be the same as new. Besides the performed GHG emission calculation was for production and displacement stages only to be compared to other pilot projects. In KA 23 the used steel profiles were relatively new in the extension construction. It has been suggested two scenarios with reused profiles for both the rolled and hollow respectively lead to a significant potential for GHG reduction per kilogram of 0.03 kg CO2 eq.

The concrete hollow-core slabs also provided clear savings, even though they have been reused to a relatively limited extent. These are examples of materials that place a great environmental impact (carbon mitigation) on production. In the literature, it is assumed that such materials will provide correspondingly large savings when reused, which seems to be significant (Asplan Viak, 2018; Naber, 2012). In comparison, the ceiling panels provide limited greenhouse gas savings overall, even though quite large amounts of the panels have been used in the project. The new alternative here is insulation, which has far lower emissions from production than steel and concrete.

For the façade cladding in KA13, It has been decided to include the surplus cladding panels of the façade in the analysis. From the theory, surplus materials are not further defined as reuse, although it is a good measure of resource efficiency (Kilvær et al., 2019). As mentioned, surplus materials were used because sufficient quantities of reused materials and products were not found. It may not be entirely appropriate to include them in this analysis as it says something about the uncertainty associated with the supply of reusable elements, but it was chosen because it opens up for interesting discussion about how correct is it to calculate these materials.

It is not clear from the standards for life cycle assessments how surplus materials are to be included in a system. It is uncertain whether it is most appropriate to include production, not include it, or include only parts of it. It is stated from the project that the materials would probably have been sent for waste treatment if they were not used in this project. Nevertheless, the products have already been produced and not used before, so it can be argued that production should be taken into account. On the other hand, the consequence of counting on the production of these materials is that it does not pay for projects to utilize such surplus materials. Thus, there will be few incentives to try to reduce waste through the utilization of products that will not be used. Based on this, it has been decided in this study not to count on the production of the materials.

To what extent can the results indicate which reusable material/product gives the best CO2 saving?

The results from the environmental system analysis show what savings the reusable products provide compared to a new alternative, in total for the project and per unit. In assessing which materials give the best effect when it comes to greenhouse gas savings, it is tempting to compare the results from the various materials. However, this is a challenge as the scope of the reuse products is different and they do not have the same functional unit, in addition to the results being project-specific. For example, how can one compare the impact of the steel components, which are stated in kg and used in large parts of the project, against the windows that are stated in m^2 of windows and are only used on certain floors?

One solution could be to look at how large parts the different materials typically make up in many different rehabilitation projects and analyze the effect of replacing all new materials with reused ones. At the same time, this opens up for discussion about how likely it is to achieve projects with 100% reuse. The results should therefore be considered separately in this study. The magnitude of the savings, especially per unit, can still indicate what pays off the most. In other words, what to be considered is the Carbon Dioxide factor per unit for the reused materials and products. To get a comprehensive picture of the savings, as much of the life cycle as possible should be taken into account. It has been seen in this study that all the materials give large savings from the first phases, but when including replacement, the savings may look a little different.

Value for future projects and generalization of project-specific results?

In future projects, assessments should be made for several building parts, with a focus on the largest amounts of material, and those that otherwise contribute to large greenhouse gas emissions. This primarily applies to concrete structures and steel structures but is also relevant for wall elements and windows. As the reuse market becomes more established, it is natural that environmental product declarations (EPD) are made for reused materials in the same way as new materials. This already exists, among other things, for façade panels of reused brick[20]. Probably results from EPDs of reusable products can be adapted to similar products, if this becomes more widespread in the market.

Experience from the projects shows that the large savings are made especially for building parts that have a long service life, such as the supporting structure in steel, but also facade panels and Hollow-core slabs contribute to large greenhouse gas savings. It is thus challenging to estimate how large parts of the completed processes that are relevant will be done in the same way in future reuse projects. Consequently, it will also be difficult to say how large parts of the environmental system analysis will be able to provide a picture of greenhouse gas savings that can be expected in the various material categories.

It is emphasized in the method that Yin (2018) argues that results should be made based on the case study and not the specific case. The results from the comparative environmental system analysis should therefore be seen in connection with theory so that

[20] https://www.epd-norge.no/bygningsplater/gamle-mursten-vagsystemer-facadesystem-med-murstenskaller-skaret-af-genbrugsmursten-article1997-318.html

they can be generalized. Here again, comes the aspect where case studies are pilot projects since there are currently few comparable projects.

In theory, two studies have been highlighted that have attempted to investigate what environmental effect reuse can have from a societal perspective (Høibye and Sand, 2018; Asplan Viak, 2018). The results in these studies are relatively divergent, partly because one study also included material recycling. The environmental system analysis in this study is too project-specific for them to be used to see potential environmental savings from a larger perspective. This has not been the goal of the thesis either, but the more specific examples one has of reuse and calculations of its environmental effect of it, the greater basis one may have to say something about the environmental effect at an overall level. However, this is closely related to how large amounts of materials can and will be reused in the future.

5.2.2 Impact of the method for calculation of environmental impact

Methodological choices made in the environmental system analysis can have a significant impact on the results of the analysis. This will be discussed in more detail here.

<u>System boundary</u>

According to NS 3720, the system limit for external reuse must be set when the material from the previous system reaches the material's «end of life» (Fuglseth et al., 2018). What this means in practice is not clear. How the various benefits and disadvantages associated with reuse are to be distributed between the various systems can also affect the results. For example, whether disassembly from the previous system should be taken into account, is not clear. In the comparative environmental system analysis carried out in this study, it has been chosen to take into account the disassembly in the analysis. This is done because the probability of demolition work being carried out in another way if the products are not reused in this project, is assumed to be relatively high. If the dismantling leads to an increase in emissions, and it falls to the demolition project, there will be few incentives to implement this. It is uncertain whether this will lead to increased emissions.

<u>Product comparison</u>

An important condition in comparative analysis is that the compared products fulfill the same function, defined by a functional unit (Bakshi, 2019; Fuglseth et al., 2018). In the environmental system analysis, it is assumed that this is true for the re-use products and a corresponding new alternative. At the same time, some challenges have been experienced in defining a good function where the technical specifications of the re-use products are different from what is often the current standard. This is especially true for windows, where the U-value could have been a natural part of the unit, to ensure the same purpose. Nevertheless, they serve the same purpose, for example in the form of letting daylight into the building and can be opened and create natural ventilation.

A further challenge with this is that the final solutions with reused products have in many cases ended up being different from what would probably have been implemented if new products had been used. This applies, among other things, to the façade cladding solution. The complex solution is probably partly chosen to be able to use the quantities of reusable boards that it has been possible to obtain from various projects. It is uncertain whether a less complex solution would have been chosen if new products had been used. In each case, the solution resulted in a large increase in the number of barges and loops used with what was initially planned.

The windows are also a clear example that the solution has become different with reusable products. Due to the higher U-value of the reuse windows compared to new windows, extra insulation has been used in the wall. Changes have also been made in the façade design, and this can be regarded as indicators that new and older windows are not completely comparable in the first place. Furthermore, the assumption that the compared products behave similarly in use and have the same maintenance needs is a simplification of reality. Today, no proven routines have been developed to be able to determine the properties of reusable products. On the other hand, the condition of the reusable materials in the project has been assessed by professionals and processing has been done that should indicate that the materials are of the required quality.

5.2.3 Resource efficiency through reuse

It has been shown in theory that reuse constitutes the second-highest step in the waste pyramid, and is thus considered the second-best management of resources after waste reduction. Reuse is thus considered a more valuable way of managing resources than, for example, material recycling or energy recovery, refer to Figure 2.5. The question of whether reuse is a good resource efficiency solution in the construction industry is not taken for granted that it is always the best resource management solution.

Asplan Viak (2020) argues for the necessity of reused materials being able to replace the role of the virgins, and not just supplement the use, to achieve holistic environmental effects. In some cases, when reusing, there may be a need to use additional materials and products, which would not have been necessary if new materials had been used. The reuse windows and the façade solution in KA13 and KA23 are examples of this, where the windows entailed a need for extra insulation and the façade solution entailed extra barges and loops. None of the parts had a major impact on the greenhouse gas accounts, but it led to an increased need for materials. In such cases, it is conceivable that an assessment should be made of what extra materials are required, as well as how large quantities, before one can say anything about which solution is best.

Ibenholt et al. (2020) point out that re-use rarely becomes one-to-one utilization, and thus often involves waste. This is partly because few buildings are designed for dismantling. If buildings were to a greater extent designed to be modular and standardized, such as «lego bricks», they could provide full utilization of the materials (Ibenholt et al., 2020). This is not the case in today's building stock, but it opens up for even greater resource efficiency in the event of reuse in the future if it is currently designed for dismantling and reuse.

The environmental system analysis has revealed that the façade solution has led to relatively large amounts of cuts. The small dimensions of the plates were chosen, among other things, so that today and in the future, there will be greater opportunities to find suitable reusable products. At the same time, this meant that larger plate dimensions had to be cut into much smaller parts, and previous attachment points also had to be removed. This can be said to be contrary to the idea that one should plan for less competition and waste in the first instance to a reduction of waste volumes from projects. On the other hand, the use of the plates also leads to an extended service life of the products and less resource consumption.

5.3 What development is it likely that the reuse market will have in the years to come?

What development the reuse market will have in the years to come is, based on this study, challenging to say something certain about. The reuse market is, as shown in theory, poorly established and constantly evolving. Many assumptions must be taken into account and barriers must be overcome for an upscaling of the market to be possible (Asplan Viak, 2018; Kilvær et al., 2019). How and when we will eventually overcome these are still uncertain to say. Based on the theory, there is admittedly great interest in reuse in the industry. Is it possible to use this moment to make changes?

There are many opinions about the future market's prospects. Today, most of the reuse in the professional market is reserved for selected pilot projects (Asplan Viak, 2018). This will also be the practice until reuse is more rational financially. Besides, more industrial solutions will be established, but only for a few, selected products. Many researchers believe the reuse of other materials will be reserved for the private market, which has great potential for upscaling. On the other hand, awareness of the climate challenges, as well as the Norwegian government's commitment to the Paris Agreement, will drive the development of the market.

An important condition that is assumed to be of great importance for the development of the reuse market is how we should relate to the legislation in the future. The Norwegian Directorate for Building Quality, DiBK (n.d.), emphasizes that work is taking place within the EU on how DOK can come to terms with a reuse practice, and it may take a long time to get in place. Kilvær believes that the experiences gained in the industry now, in pilot projects such as KA13 and KA23, will be able to contribute to finding accepted solutions and practices for selected building materials before that time. The Norwegian Directorate for Building Quality (DiBK) will crackdown on illegal activity, and in turn, emphasizes the importance of spending enough time to put in place safe solutions.

Several aspects of the reuse market development are characterized by a "hen and egg" situation, as Sunde et al. (2018) draw attention to. This makes it difficult to secure needs and demand. Builders do not dare to order something that may be unsafe, at the same time suppliers will not provide reused products if there is no clear demand. The Norwegian Directorate of Public Construction and Property (Statsbygg) and Norway's largest housing developer (OBOS) agree that the large builders must secure the demand by ordering power, and in this way, it may be that other players in the market adapt (Kilvær et al., 2019). Sunde et al. (2020) believe that this is central to getting the market going. Asplan Viak (2018, 2020) highlights cooperation between players as central to an upscaling of the market. Cooperation can help to find safe and good solutions to the challenges and at the same time reduce the risk for players who want to contribute to the development of the market.

At the time of writing, several players are in the process of establishing a well-functioning marketplace for reuse. It can help to visualize quantities of different products and make it easier for projects to plan with reuse in their projects. This will ensure the predictability of supply, and at the same time make it easier for the demand side to choose reuse. However, a marketplace is not a stand-alone solution that will lead to the development of the market, and more information is also required about existing building materials. The importance of putting in place sufficient information to be able to make a qualified choice about when it may be appropriate to choose reusable products in projects. As material passes are central, Madaster stated in a breakfast meeting under the auspices of Circular Norway that "if we do not know what it is, we throw it away" (Thorendal, 2019).

Furthermore, a change in attitudes related to re-use in society could have a significant impact on development. People are used to surrounding themselves with new things, and that new and rehabilitated building should not bear the mark of having collected what they have on hand. Users on the other hand are not willing to pay large sums for something that is several years old. This is about what attitudes and expectations one has towards products and what one surrounds oneself with. In such a way of thinking, it is conceivable that it may be easier to reuse products that are not visible in the building, such as support systems and the ceiling panels in KA13, and KA23 that are used above the ceiling. At the same time, the case projects are good examples of how reuse can also lead to a type of identity or architectural style, which can be desired and intended. The circular economy has become a trend, and more people are following the green wave. It is conceivable that increased awareness of environmental challenges and the need for sustainable development may change expectations and lead to a greater desire for sustainable solutions and reuse among users. This can potentially provide an increased pretext for implementing reuse if there is demand in the market, from both builders and users.

The opportunities can be created by thinking completely new about ownership and the use of building materials in construction. Increased producer responsibility and leasing agreements for products will create increased incentives for manufacturers to produce their products more durable, and to a greater extent facilitate disassembly and reuse. Then the need and service the product complements will be in focus to a greater extent, than the product itself. This is a key aspect of the circular way of thinking (Green Building Alliance and Norwegian Real estate, 2016; Boye 2019; Bakshi, 2019). If this becomes more relevant, there may also be completely different financial and legal framework conditions to deal with. It can give the market other dimensions than what is focused on in this thesis.

As previously discussed, the reuse potential of existing buildings will look completely different when buildings designed for dismantling and reuse reach their functional or technical life. This is a two-part problem, where the reuse of current materials and products offers greater challenges than it will in the future. Is it still worth investing in reuse today, even though as of today many barriers must be overcome?. As theory has shown, the world's resources are under great pressure, and we must also introduce further measures that can contribute to reduced greenhouse gas emissions now and until 2030 if it is to be possible to comply with the Paris Agreement. The environmental system analysis has shown that reuse can both contribute to large greenhouse gas savings and more efficient use of resources. The question is whether we can find good and competitive solutions for the materials and products that are based on the greenhouse gas accounts.

5.4 How do FutureBuilt circular building criteria comply with BREEAM-NOR v.06

As described in the theory, FutureBuilt circular building criteria have a goal to raise awareness about circularity and for the criteria to be easy to apply (Nordby,2020). The greater goal was to link the criteria to already established Norwegian standards and guidelines. BREEAM-NOR (2022) by their new assessment manual v6.0 has utilized the FutureBuilt circular building criteria as an Exemplary level reward. On the other hand, FuturBuilt is trying to comply with the BREEAM-NOR v6.0 to improve their circular building criteria from one side and make it more compatible with BREEAM-NOR v.06 criteria set from the other side. The overall aim was to standardize and spread knowledge about calculating how circular buildings, materials, and products are. The intention is to encourage both the investors and building owners toward renovation and improve the practice in buildings that invest in the reuse of materials and products. In the theory, it has been concluded five corresponding parameters for both FutureBuilt- and BREEAM-NOR v.06 criteria; material efficiency, material reuse, GHG emission calculation, resource utilization, and waste volume.

Material efficiency and material reuse are among the most important building circularity indicators. The good utilization of material efficiency and reuse in the construction industry can promote reuse and optimize the use of new materials. According to BREEAM-NOR v.06 (2022), project-specific goals and measures must be prepared to increase material efficiency. For example, the land use can be optimized through joint use and sharing, increasing the utilization rate of building elements or design with standard dimensions to reduce lost spaces and avoid oversizing. The use of materials and products that can be reused or recycled at the end of their service life can also be a solution. Also, reuse of building elements or use of materials with a high proportion of recycled content. However, increasing material efficiency can also be by (DfD) design for disassembly and reuse, using prefabricated items where appropriate to reduce material waste, or utilizing thermal mass for heat storage by exposing materials with good heat capacity. Extra loads can be avoided, for example, avoid oversizing loads and design with light load-bearing structures or use tailor-made load-bearing structures where this will reduce the use of materials. In other words, rationalize the use of load-bearing structures and optimize solutions for soil and foundations. Furthermore, the responsible procurement of materials also plays an important role. It can promote the choice of materials with lower negative environmental, economic and social impacts throughout the supply chain, including extraction, processing, and production. As mentioned under the material category, Mat 03 (BREEAM-NOR, 2022).

FutureBuilt on their criteria section 2.3 "reuse of building materials" required that at least half of existing building structures, calculated by weight, must be taken care of (Nordby,2020). Increasing the material efficiency measure is by the preservation of existing building structures, which also counts as reuse in the reuse accounts. In addition, they added that at least 10% of the components supplied to the building must be reused, and reuse must be carried out for min. 5 component types. This opened up a discussion about the weight percentage calculation and the number of components. BREEAM-NOR s consultant, Siri Reed, argued that calculation based on weight only leaves the lightweight components as electrical equipment and technical excluded from the reuse field. So they have decided to include only the number of components or measures instead of the weight percentage in their material category, Mat 06 (BREEAM-NOR, 2022).

GHG emission calculation is categorized due to project phases. Preparing a greenhouse gas budget in the early phase can be used to design own climate goals and help to concretize sustainability goals and strategies in the project. Comprehensive calculation of buildings' greenhouse gas emissions throughout the building's life cycle provides an opportunity to identify measures to reduce greenhouse gas emissions from both a short and long time perspective. After construction, a comprehensive greenhouse gas account with as-built information will be presented. The scope shall be the same as for the greenhouse gas budget. The results are registered in the BREEAM-NOR auditor's report. The project management will review the results and see how they correspond to or deviate from the sustainability goals set in the project, refer to management category, Man01, criteria 2,3 (BREEAM-NOR, 2022). As BREEAM-NOR recognizes that greenhouse gas calculations are a field under development. It is possible that projects that use FutureBuilt ZERO version 2.0, dated 14.06.2021, can use this set of criteria and methods to document the project's total greenhouse gas emissions. In FutureBuilt ZERO method note version 2.0, dated 14.06.2021, the assumptions and deviations from NS3720: 2018 are explained in detail. The note can be found on FutureBuilt's quality criteria (Andresen et al., 2021).

Resource utilization, according to BREEAM-NOR v.06 (2022), aims to reduce the amount of construction waste by designing and facilitating reuse, recycling, and best practice management of resources and waste on the construction site. A resource management plan shall be prepared, which includes the design and management of construction waste, demolition waste, and excavated masses. If there are existing structures in the development area, as in our case study projects, the resource management plan must be prepared in connection with the reuse mapping report from the issue Mat 06; Material efficiency and reuse. Such a plan aims to promote resource efficiency and prevent the illegal disposal of such waste. Furthermore, construction and demolition waste should be prepared for reuse and material recycling. The Preparation for reuse and material recycling means that the waste can be used for; reuse for similar purposes, material recycling for new products, or filling material within the construction area or on other plots within a reasonable surrounding distance. For such recovery of concrete and bricks, the waste regulations §14a must be followed. Other material that can be utilized must be approved by the relevant authority.

For resource utilization, FutureBuilt criteria for circular building (Nordby,2020), states that an account shall be given of how resource utilization in the demolition phase is planned and implemented (resource management plan in BREEAM-NOR v.06) Reusable components must be mapped taking into account the potential for reuse early in the project so that the material values are made visible to the designers. Besides, Reusable components that are not used in the project must be made available to external stakeholders or sought to be returned to the manufacturer. Furthermore, sufficient time must be set aside for selective demolition/gentle dismantling, and requirements for demolition methods must be incorporated in tender documents and contracts. Dismantling and securing of components for reuse are specified in the demolition description, and requirements are set for understanding the task and references when awarding a contract.

For the Waste volume, the demolition waste, excavation masses, and waste from construction site offices and the operation of the building shall not be included in the amount of construction waste generated from the development area (BREEAM-NOR, 2022). FutureBuilt defines that during the construction phase, waste volume must be minimized including coats, wastage, packaging as well as incorrectly ordered products, and surplus products must be limited as much as possible. Where it does occur, measures must be taken to utilize these resources. New products (incorrect orders and surplus products) must not be thrown away, these must either be returned to the manufacturer, or made available to internal and external stakeholders (Nordby, 2020).

According to BREEAM-NOR v6.0, if separate return schemes have been established with suppliers or producers for products that are considered waste, in addition to an agreement with waste reception, these quantities must also be entered in the accounts of generated waste quantities. Although demolition and excavation masses are often the largest amounts of waste in a development project, BREEAM does not include this in the reporting of waste quantities, because the quantities produced vary from development project to development project. If demolition and excavation masses should have been taken into account it would not encourage development areas with inevitably large amounts of demolition and excavation masses to concentrate on reducing the production of waste from building materials (which would also have benefited environmental consequences), and it would make it easier to meet the given threshold values for waste quantities in development projects with little or no tear or digging masses. This will weaken the factors that lead to lower production of construction waste arising from the use of new building materials.

Thus, BREEAM-NOR v.06 criteria set and Futurebuilt circular building criteria tend to have many corresponding categories and issues as illustrated before in figure 2.19. BREEAM-NOR new v.06 has included the FutureBuilts criteria in their exemplary rating level. On the other hand, FutureBuilt also working on, among other quality criteria, improving the circular building criteria and linking it to BREEAM-NOR and other Norwegian standards in the building industry. Reuse as a sustainability platform and circularity assessment method can reunite, standardize and spread knowledge about Calculating how circular buildings, materials, and products are in the future construction and renovation practice.

6 Conclusion

6.2 Which building materials and products are suitable to reuse from a sustainability perspective?

The study has shown that it is not straightforward to say which building materials and products are suitable to reuse from a sustainability perspective, as a comprehensive assessment of many different aspects is required. First and foremost, it must be legal, safe, and practically feasible to reuse the building material/product. Then an assessment must be made of what is suitable depending on the ambition level of the project, what the goal of the reuse is, and what alternative solutions for resource management are. The environmental aspect of sustainability, Greenhous gas emission in this study, has been the main focus of the analysis, and the results indicate that reuse in most cases provides good greenhouse gas savings. At the same time, it has become clear that not all reuse with the current market situation and framework conditions is necessarily related to the economic aspect of the concept of sustainability. This makes it challenging to achieve something more than just pilot projects. However, changes in the framework conditions and market structure in the years to come will be able to change this picture.

The scope of work of what can be reused is limited by the legal framework. The possibilities for disassembly and transport without damage also place limits on what is practically possible to achieve. Furthermore, for it to be more worthwhile to choose reuse over a new product, the building product must be of a certain quality and be able to fulfill the desired function without leading to the need for large amounts of extra materials, as well as having a sufficient remaining life. There must also be sufficient quantities of similar materials to be obtained to put reuse processes associated with the relevant material to a greater extent in the system. There must also be sufficient quantities of similar materials to be obtained to put reusable processes associated with the relevant material to a greater extent in the system. In this perspective, the large waste fractions, such as wood, concrete, and steel, are worth investing in. Products that do not have special requirements, such as furniture, floor surfaces, and landscape architectural products, are far easier to reuse. Here, aesthetics and quality mainly determine what is usable.

In the study, Greenhouse gas savings are compared with a new product alternative calculated per building part, building material/product, and for selected corresponded material categories in connection with the case projects Kristian August gate 13 and Kristian August Gate 23. The results of this analysis are based on project-specific conditions but can contribute as an experience base. The comparison per building part was based on building parts schedule, 2-digit level. The calculations show that emission reductions from the material use of 83 % or (3.57 kgCO2eq./m²/year) and 70% or (6.45 kgCO2eq./m²/year) are achieved for the whole building for KA23 and KA13 respectively. In the comparison per material/product the following categories were considered: Steel, Concrete, Glass, doors and windows, Gypsum, Timber, Façade Cladding, Brick, Insulation, Ceiling panels and Floor covering. The most significant reductions were scored by the steel and concrete categories. The following material categories were further analyzed in detail: Steel, Hollow-core slabs, windows, Brick, and Facade panels. From the production phase together with the replacement of the building components, all the products provided between 78% and 98% savings compared to a new alternative. Corresponding savings are also shown in previous studies. Durable reuse Material/product that does not need replacement will thus to a large extent pay off environmentally, and total savings will depend on how energy-intensive the production of new similar materials is. In this sense, load-bearing materials, such as steel and concrete, are examples of materials that can have good effects.

In general, the reused steel profiles give by far the largest environmental effect of the analyzed material categories in the case projects and contribute to a reduction of about 110 tons of CO2 equivalents. Here, the theory indicates that it should be possible to put in place good solutions so that both internal and external reuse is possible. Load-bearing steel components can thus be considered suitable to invest in for reuse. Then follow reused brick as a good solution despite the technical problems experienced with the firewall construction in KA13. The windows have been shown to have an impact on the project's energy accounts, but still, come out well from the analysis. The remaining service life and U-value will be central to whether the reuse of windows can be described as suitable reuse. The hollow-core slabs can have great potential, depending on how extensive the handling is and the extent of the reuse. The façade solution in KA13 largely consists of surplus materials, as it has been challenging to find reusable products. Here, the analysis has revealed that clarifications are required about how the environmental impact of surplus materials is to be calculated in the project. Without including production, the façade solution provides good greenhouse gas savings.

A selection of reused products has been analyzed in-depth in this study, but the other materials and products also have great reuse potential. The latter material categories were selected on the comparison- and the corresponding ability basis for case projects KA13 and KA23. In the study, the glass and floor covering are believed to have great potential, among other categories. Experience from implementation is required here to be able to say something more about what is suitable from a sustainability perspective. Furthermore, it is important that what can be considered suitable must be seen in connection with current recycling solutions, as well as other measures that can provide increased resource efficiency and reduced greenhouse gas emissions in the construction industry.

If we avoid substances that are harmful to health and the environment and put in practice more improved design methods such as (DfD) "design for disassembly" and flexible solutions in construction projects, far more building materials and products may be suitable to reuse in the future. On the other hand, this will only have a lasting effect in the future, and the reuse of certain materials may represent sustainable solutions already now.

6.3 What is the potential for upscaling the re-use market?

Today's re-use market is a little set in the system and constantly evolving. In a project-based industry with strict time and cost limits, as well as well-established and well-proven processes, reuse currently entails some uncertainties. A clarification is constantly required in connection with legal aspects and what is possible to achieve from legal re-use. Furthermore, there is a lack of information about used building materials, as well as information about what will be made available from demolition and rehabilitation activities in the future. This creates unpredictability in what may be possible to obtain. Lack of financial incentives in combination with a poorly developed market structure and lack of accepted practice currently limits the possibilities for an upscaling of the re-use market.

Nevertheless, there is a great deal of interest and ever-increasing ambitions associated with reuse in the current industry. Several initiatives work towards establishing a functioning practice, so that reuse can be carried out to a greater extent in the industry. Ongoing and planned pilot projects can contribute valuable experiences related to how reuse can be implemented in projects.

Trends in construction and demolition activity have been used to provide a picture of what the development might look like. The rehabilitation and conversion activity around commercial buildings will probably continue to increase, as has been the trend in recent years. 80 percent of the building stock is expected to remain standing in 2050, but at the same time more and more is being built than is being demolished in the face of population growth. With an increased focus on area efficiency and preservation of buildings, one will probably see an increased need for necessary interventions in existing buildings. At the same time, it is conceivable that demolition activity will decline, as complete demolition of buildings is less compatible with sustainability thinking.

The design of buildings will also be central to the possibility of an upscale reuse market in the fututre. The study has shown that the reuse of building materials from the current building stock can in many cases be challenging and also expensive in some cases. This is justified, among other things, by the fact that many buildings are designed with low adaptability and without the thought that they can be used further at the end of their functional life. As predicted, the building of the future will set other requirements for design, and it is essential to prioritize design that takes into account adaptability and design for disassembly and reuse, regardless of whether it is new construction or rehabilitation. The materials must also be developed and improved to reduce the content of environmentally hazardous substances and increase durability. The effects will only be seen in the future, but with this as a starting point, there will no longer be a need for functional changes in buildings that will put an end to the cycle for buildings and building materials. Instead, technically and environmentally safe service life will be limited.

Furthermore, it is emphasized that reuse must be seen in connection with other existing methods for resource utilization and material efficiency, as well as for reducing greenhouse gas emissions measures. Although reuse is considered a high-quality method for resource management and in many cases refers to significant environmental savings, it is beneficial for the industry that the practice is assessed against waste volume minimization and recycling. Some materials are not suitable for reuse today and then other solutions may be a more favorable alternative.

In this study, it has been concluded that reuse on a larger scale can have the greatest potential by prioritizing certain material categories. This is to be able to develop systems that can provide profitable processes both financially and environmentally for an entire industry. Which material categories there should be is currently not straightforward to say, because it depends on which products we can find solutions for, among other things, disassembly, logistics, testing, re-documentation more in the system, and where it is also possible to get the economy to go up. Nevertheless, the study has assessed some materials that may appear to have great potential.

What development the reuse market will have, and what role reuse can play in the work of developing a greener and more sustainable construction industry, is still uncertain. Future development depends on different aspects, many of which are highlighted in this master's thesis. Experiences gained in the industry at the time of writing and in the time to come will be able to have a great influence on how the development will be. This study has shown that there can be great environmental benefits to be gained from reuse, in the form of resource and greenhouse gas savings. The question is what role the industry's players and the authorities will take in future developments, as well as how the reuse of various building materials and products can be linked to the economic aspects of the concept of sustainability in the years to come.

Construction industry players and authorities, such as Oslo Municipality and Green Building Alliance, are playing an important role in reuse market development. Six municipalities, for example, in the Oslo region, are collaborating on the FutureBuilt program to support climate-friendly urban development. FutureBuilt contributes with its quality criteria, among the others, circular building criteria. While Green Building Alliance, the operator of the environmental certification method "BREEAM-Nor v.06" has adopted the reuse of building materials in their new version to a relatively good extent. How do FutureBuilt circular building criteria comply with BREEAM-NOR v.06., as shown in the study, embodied with their goal to link the criteria to Norwegian standards and guidelines, among the others, BREEAM-NOR v.06 criteria set. BREEAM-NOR on its new version v.06 has employed the FutureBuilt circular building criteria on its Exemplary level. On the other hand, FuturBuilt is trying to comply with the BREEAM-NOR standards to improve its criteria and make it more compatible with BREEAM-NOR v.06 criteria set. The goal was to standardize and spread knowledge about calculating how circular buildings, materials, and products are. The intention is to encourage both the investors and building owners toward renovation and improve the practice in buildings that invest in the reuse of materials and products. In conclusion, five corresponding parameters are specified; material efficiency, material reuse, GHG emission calculation, resource utilization, and waste volume.

6.4 Recommendations for further work

The study has dealt with several aspects of reuse that may be interesting to go into even more depth than what has been relevant here. Some aspects are requested in several other reports, such as looking to other countries for re-use experiences, but the study has also revealed some new elements that may be useful to gain more insight into.

It will be very beneficial to get a clearer overview and an expanded knowledge of the building stock, with material composition and the need for upgrading. This is especially true for commercial buildings, where there is limited available information as of today. Furthermore, it would be interesting to take a closer look at how reuse can be made visible in the waste statistics, as well as possibly how the waste statistics can to a greater extent clarify which materials and products the various material fractions contain.

Carrying out the environmental system analysis of the reusable materials in the case project proved to be a comprehensive and time-consuming process. As there is a focus in the industry on making the environmental aspects of reusable materials visible, it may be interesting to investigate what a more efficient approach might look like. A more standardized and simplified method for determining greenhouse gas emissions for other reusable materials will, to a greater extent, enable the comparison of systems. In addition, it can be a useful tool in assessing whether reuse is worth prioritizing in each case. It will also be interesting to look at which other environmental impact categories can have a major impact, in addition to greenhouse gas emissions in such analyzes.

Finally, it would be interesting to take a closer look at which methods of resource management, including reuse and material recovery, pay off financially and environmentally for each material. Relatively for the entire life cycle, including scenarios for changes in framework conditions in the future to look at what the effects will be if reuse is to a greater extent put into a system.

References

Addis, B. (2012). *Building with reclaimed components and materials: a design handbook for reuse and recycling*. Routledge.

Akanbi, L. A. *et al.* (2018). Salvaging building materials in a circular economy: A BIM-based whole life performance estimator, *Resources, Conservation and Recycling*, 129, s. 175-186. Available from: https://www.sciencedirect.com/science/article/pii/S0921344917303609.

Akinade et al.(2017). *Design for Deconstruction (DfD): critical success factors for diverting end-of-life waste from landfills*. Waste Manage. 60, 3–13. Available from: https://doi.org/10.1016/j.wasman.2016.08.017.

Andresen, et al. (2021). *FutureBuilt ZERO - Criteria, calculation rules and documentation requirements.* Future Built quality criteria, Published 14.06.2021, Rev.02. Available from:https://www.futurebuilt.no/FutureBuilt-kvalitetskriterier.(Retrieved Mar 17, 2022)

Arge, K. & Landstad, K. (2002). *Generality, flexibility and elasticity in buildings.* Available from:https://www.sintefbok.no/book/index/175/generalitet_fleksibilitet_og_elastisitet_i_bygninger. (Retrieved: Jan 28, 2022).

Asplan Viak (2018). *Investigation of barriers and opportunities for reuse of building materials and technical installations in buildings.* Available from:http://www.byggemiljo.no/wp-content/uploads/2018/10/NHP-Barrierer-for-ombruk-v4.pdf. (Retrieved: Feb 8., 2022).

Asplan Viak (2019). *The Building And Construction Sector's Greenhouse Gas Emissions. An overview of GHG emissions that can be attributed to the building, construction and real estate sector (BAE) in Norway* .Available from: https://www.bnl.no/siteassets/dokumenter/rapporter/klimautslipp_bae_2019.pdf (Retrieved: 5. February 2022).

Asplan Viak (2020). Project: *Climate-friendly building materials - Potential for emission reductions and barriers to use*. Available from: https://www.asplanviak.no/prosjekter/klimavennlige-byggematerialer-potensial-for-utslippskutt-og-barrierer-mot-bruk/. (Retrieved: Mar 12, 2022)

Asplan Viak Reuse (2022). AV Reuse: *a system for reuse mapping and design of used building materials.* Available from: https://www.asplanviak.no/verktoy/ombruk/.

Aveyard, H. (2019). *Doing a literature review in health and social care: A practical guide* (4th ed.). London: Open University Press/ McGraw- Hill Education.

Bakshi, B. R. (2018). *Including Nature in Engineering for Innovation and Sustainability: Promise, Progress and Peril.* Volume 44, pages 53-62. Available from: https://www.sciencedirect.com/science/article/abs/pii/B9780444642417500069

Bakshi, B. R. (2019). *Sustainable Engineering- Principles and Practice.*

BAMB (2019a). Buildings as Material Banks: *About BAMB*. Available from: https://www.bamb2020.eu/about-bamb/. (Retrieved: Feb 12, 2022).

BAMB (2019b) *Framework for policies, regulations, and standards*. bamb2020. EU: *Buildings As Material Banks*. Available from: http://www.bamb2020.eu/wpcontent/uploads/2019/02/BAMB-Framework-for-Policies-Regulations-and-Standards-withappendices.pdf (Retrieved:Feb 12, 2022).

Bjørberg, S., Kampesæter, A. og Listerud, C. A. (2009). *Lifespans in practice - Principles and uses*. Multiconsult. Available from: https://dibk.no/globalassets/eksisterendebygg/publikasjoner/levetider_i_praksis.pdf.

Bjørheim, K. (2018). *IBM's digital twin will help the construction industry to become sustainable*. Available from: https://www.tu.no/artikler/ibms-digitale-tvilling-skal-hjelpe-byggenaeringen-a-blibaerekraftig-br/449543. (Retrieved: April 12, 2022).

Bohne, R. A. & Wærner, E. R. (2014). *Barriers for Deconstruction and Reuse/Recycling of Construction Materials in Norway*. Available from: https://www.researchgate.net/publication/264671518_Barriers_for_Deconstruction_and_ReuseRecycling_of_Construction_Materials_in_Norway. (Retrieved: April 25, 2022)

Boye, E.(2019). *Circular future- about the shift from linear to a circular economy*. Available from: https://www.framtiden.no/aktuelle-rapporter/874-sirkulaer-framtid-om-skiftet-fra-lineaer-tilsirkulaer-okonomi/file.html.(Retrieved: Mar 20,2022).

Bramslev, K. (2018). *The importance of the construction and real estate sector for greenhouse gas emissions.* Available from: https://www.bygg21.no/contentassets/901dbc37a0c242229f4d8248a12919dc/33019_delrappor t-3b_digitalt.compressed.pdf.(Retrieved: Mar 12, 2022).

Brand, S. (1997). *How buildings learn: What happens after they're built (Rev. ed.).* London: Phoenix Illustrated.

BREEAM (n.d.). *Building Research Establishment's Environmental Assessment Method*.. https://bregroup.com/products/breeam/. (Retrieved: May 3, 2022).

Breivik, J. K. (2017). Oria, articles and source reviews on 1-2-3: *NTNU University Library's subject page for science.* Available from: https://www.ntnu.no/blogger/ub-realfag/2017/02/22/ta-i-bruk-oria/. (Retrieved April 22, 2022).

Building Case Regulations (2010). *Building Regulations (CASE10).* Available from: https://lovdata.no/dokument/SF/forskrift/2010-03-26-488 (Retrieved: Feb 20,2022).

Building Technical Regulations (2017). *Regulations on technical requirements for buildings.* TEK17. Available from: https://lovdata.no/dokument/SF/forskrift/2017-06-19-840. (Retrieved: 26.04 2022).

Butera, S. et al. (2016). *Material atlas of building materials' recycling and recycling potentials: An InnoBYG project*. Available from: https://issuu.com/www.innobyg.dk/docs/materialeatlas. (Retrieved: Mar 26, 2022).

Bygg21 (2018a). *10 quality principles for sustainable buildings and areas*. Oslo. Available from: https://bygg21.no/wp-content/uploads/2021/03/33019_delrapport-3a_digitalt.compressed.pdf. (Retrieved Mar 25, 2022)

Bygg21 (2018b). *Good buildings and areas - for health, the environment and the wallet, Commissioned by the Ministry of Local Government and Modernization*. Available from: https://www.bygg21.no/rapporter-og-veiledere/gode-bygg-og-omrader---for-helsa-miljoet-oglommeboka/4.0-bygg21s-anbefalinger/?q=sirkul%C3%A6r (Retrieved: Mar 27, 2022).

Camacho et al. (2018). *Consumption in the circular economy: a literature review*. *Sustainability 10*. https://doi.org/10.3390/su10082758.

Chaudhary, M. (2019). *Less for material recycling.* Available from: https://www.ssb.no/natur-ogmiljo/artikler-og-publikasjoner/mindre-til-materialgjennvinning. (Retrieved: May 12, 2022).

Circular Economy *et al.* (2018). *A framework for circular buildings- Indicators for possible inclusion in BREAM*. Available from: https://www.circle-economy.com/wp-content/uploads/2018/10/AFramework-For-Circular-Buildings-BREEAM-report-20181007-1.pdf. (Retrieved: Feb 5, 2022).

Circular Norway (2019). *Waste is material that does not have an identity*. Available from: https://www.circularnorway.no/post/avfall-er-materialer-som-ikke-har-en-identitet (Retrieved: Mar 15, 2022).

Cobuilder (2018). *The digital twin - the bridge between the physical and the digital world.* Available from: https://cobuilder.com/nb/den-digitale-tvillingen-broen-mellom-den-fysiskeog-den-digitale-verden/. (Retrieved: May 4, 2022).

Creswell, J. W. (2014). *A concise introduction to mixed methods research*. SAGE publications.

Debacker, W., Manshoven, S., & Denis, F. (2016). D1 Synthesis of the state-of-the-art: key barriers and opportunities for materials passports and reversible building design in the current system. BAMB 0-103. Available from: https://www.bamb2020.eu/wp-content/uploads/2016/03/D1_Synthesis-report-on-State-of-the-art_20161129_FINAL.pdf

DFØ (2021) *New tool for low greenhouse gas emissions in construction projects.* The Directorate for Administration and Financial Management. Published: March 2, 2021. Updated: March 4, 2021. Available from: https://anskaffelser.no/nn/nyhetsarkiv/2021/03/nytt-verktoy-lage-klimagassutslepp-i-byggjeprosjekt. (Retrieved: May 6, 2022).

DiBK (2016). *The Directorate for Building Quality: Regulations on documentation of building materials (DOK)*. Available from: https://dibk.no/byggeregler/dok/i/1/. (Retrieved: Mar 20, 2022)

DiBK (2017a). *The Directorate for Building Quality: Guidance on technical requirements for buildings. Building technical regulations (TEK17) with guidance. Entry into force 1 July 2017*. Available from: https://www.regjeringen.no/contentassets/20503ddfe0664fac9e2185c1a6c80716/veiledningtil-byggteknisk-forskrift-tek17_01_07_2017.pdf. (Retrieved: Feb14 2022).

DiBK (2017b). *The Directorate for Building Quality: The EU is considering a revision of the Building Products Ordinance.* Available from: https://dibk.no/omoss/Nyhetsarkiv/eu-vurderer-revisjon-av-byggevareforordningen/ (Retrieved: Feb 14, 2022).

DiBK (2018). *The Directorate for Building Quality: Reuse of building materials - what requirements must be met?*. Available from: https: //dibk.no/verktoy-og-veivisere/energi/ombruk-av-byggevarer--hvilke-krav-maoppfylles/ (Retrieved: Feb 11, 2022).

DiBK (2019). *The Directorate for Building Quality: Reuse is demanding, but not impossible.* Available from: https://dibk.no/omoss/Nyhetsarkiv/ombruk-er-krevende-men-ikke-umulig/. (Retrieved: Feb 12, 2022).

DiBK (2021). *Directorate for Building Quality: Input meeting on the Guide for the Reuse of Construction Products. Directorate for Building Quality*. Available from: https://dibk. no/om-oss/Kalender-DiBK/innspillsmote-om-veileder-for-ombruk-av-byggevarer/. (Retrieved April 3, 2022)

Difi (2019). *Circular Procurement*. Available from: https://www.anskaffelser.no/samfunnsansvar/sirkulaere-anskaffelser. (Retrieved: Feb 05, 2022).

Dunant et al.(2017). Real and perceived barriers to steel reuse across the UK construction value chain. Resour. Conserv. Recycl. 126, 118–131. Available from: https://doi.org/10.1016/j. resconrec.2017.07.036.

Ellen McArthur Foundation (2018). Growth within A circular economy vision for a competitive Europe. Available from: https://www.ellenmacarthurfoundation.org/assets/downloads/publications/EllenMacArthurFou ndation_Growth-Within_July15.pdf.

Elverum, T. (2020). *What obstacles does the architect believe the regulations set for increased reuse today?* Example from a reuse project. Mad Architects. (ed.). *Construction Waste Conference: The Building Environment*. Available from: https://www.byggemiljo.no/wp-content/uploads/2020/02/Dag1_1320-1340_Trond-Elverum.pdf.

EPD-Norway (n.d.-a). *What is an EPD?* Available from: https://www.epd-norge.no/hva-er-en-epd/ (Retrieved: April 1, 2022).
EPD-Norway (n.d.-b). *What types of EPDs exist and how are they different?.* Available from:https://www.epd-norge.no/getfile.php/139193-1531476240 / Documents / Which% 20types% 20EPDs% 20find% 20and% 20how% 20s% 2 0de% 20different% 20corr% 20signe110718.pdf (Retrieved: March 4, 2022).
EPD-Norway (n.d.-c). *Instructions for use: how to interpret EPDs*. Available from: https://www.epdnorge.no/getfile.php/1365701470750719/Dokumenter/Bruksanvisning%20tolke%20EPDer/Bruksanvisning%20for%20E PD% 20-% 20byggevarer.pdf (Retrieved: Mar18, 2020).
Estate news (2019). *Sold Kristian Augusts gate 23 for 450 million*. Available from: https://www.estatenyheter.no/transaksjon/solgte-kristian-augusts-gate-23-for-450-millioner/250716
European Commission (2015). *Closing the loop- An EU action plan for Circular Economy*. Brussels. Available from: https://eur-lex.europa.eu/resource.html?uri=cellar:8a8ef5e8-99a0-11e5-b3b701aa75ed71a1.0012.02/DOC_1&format=PDF.
European Commission (2018). Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on Waste and Repealing Certain Directives. Available from: https://ec.europa.eu/environment/topics/waste-and-recycling /waste-framework-directive_en. (Accessed 16 May 2022).
Fuglesang, A. (2017). *BIM in use phase – a qualitative mapping study of status when using BIM in the use phase*. Available from: https://ntnuopen.ntnu.no/ntnu-xmlui/bitstream/handle/11250/2464811/2017_ORD_Masteroppgave_Anne%20Fuglesang.pdf. (Retrieved: Mar 23, 2022).
Fuglseth et al. (2018) Assessment of lifecycle-based environmental requirements in TEK. asplanviak.no, dibk.no. Available from:https://dibk.no/globalassets/02.-om-oss/rapporter-ogpublikasjoner/utredning_av_livslopsbaserte_miljokrav_i_tek_asplan_viak_2018.pdf. (Retrieved: Mar 22, 2022)
FutureBuilt (2020). *Kristian Augusts gate 13. Last updated 6 Dec 2021*. Available from: https://www.futurebuilt.no/English/Pilot-projects#!/English/Pilot-projects/Kristian-August-gate-13-Oslo. (Retrieved: May 20, 2022).
FutureBuilt (2021). *Kristian Augusts gate 23. Last updated 17 Jan 2022*. Available from: https://www.futurebuilt.no/English/Pilot-projects#!/English/Pilot-projects/Kristian-Augusts-Gate-23-Oslo
Geissdoerfer, M. *et al.* (2017) The Circular Economy–A new sustainability paradigm?, *Journal of cleaner production*, 143, s. 757-768. Available from: https://www.sciencedirect.com/science/article/pii/S0959652616321023.
Gorgolewski, M. (2008). *Designing with reused building components: some challenges, Building Research & Information*, 36(2), s. 175-188. Available from: https://www.tandfonline.com/doi/full/10.1080/09613210701559499 (Retrieved:
Gorgolewski, M. (2009). *Reusing Buildings and Components*. Available from: https://oaa.on.ca/professional%20resources/sustainable%20design/reusing%20buildings%20a nd%20components (Retrieved: Mar 11, 2022).
Gorgolewski, M. and Morettin, L. (2009) The process of designing with reused building components, Lifecycle Design of Buildings, Systems and Materials, s. 105.
Green Building Alliance (2019). *Think twice before demolishing - Tips for carrying out a successful construction project without demolishing*. Available from: https://byggalliansen.no/wp-content/uploads/2019/11/Think-twice-before-demolishing.pdf (Retrieved: May 7, 2022).
Green Building Alliance (2020). *Inputs to BREEAM-NOR 2021*. Available at: https://byggallia nsen.no/wp-content/uploads/2020/11/Stakeholder-engagement-and-analysis- BREEAM-NOR-2021-report.pdf. (Retrieved: April 16, 2022).

Green Building Alliance (2021). *Reuse mapping and order - this is how you do it.* https://byggalliansen.no/wp-content/uploads/2021/08/Ombrukskartlegging-og-bestilling-%E2%80%93-slik-gjor-du-det.pdf.(Retrieved: Mar 25, 2022)

Green Building Alliance (2022). *BREEAM_NOR v6.6 New Construction*.Technical Manual SD5076NOR, updated 17.03.2022. Available from: https://byggalliansen.no/wp-content/uploads/2022/03/BREEAM-NOR-v6.0_NOR.pdf (Retrieved: April 18, 2022).

Green Building Alliance (2022a). *The most important changes in BREEAM-NOR v6.0.* Available from: https://byggalliansen.no/wp-content/uploads/2022/03/De-viktigste-endringene-i-BREEAM-NOR-v6.0.pdf (Retrieved: April 20, 2022).

Green Building Alliance and Norwegian Real Estate (2016) The real estate sector's roadmap towards 2050. Available from:https://byggalliansen.no/wp-content/uploads/2018/11/Eiendomssektorens-veikart-mot2050.pdf.

Guy, B., Shell, S. (2002). *Design for deconstruction and materials reuse*. In: Proceedings of the CIB Task Group 39.

Hagen, R., Haupt, H. M. and Bramslev, K. (2017) Green Material Guide - Guide to environmentally sound material selection. Green Building Alliance and Context AS. Available from: https://byggalliansen.no/wp-content/uploads/2018/11/Gronn-Materialeguide-V2.pdf.

Hambra and Hjellnes Consult (2013). *Avoid health and environmentally harmful substances in construction - a guide for builders, designers, and contractors*. Available from: https://dibk.no/globalassets/miljo/publikasjoner/substitusjonsveileder_print.pdf.

Hart et al.(2019). Barriers and drivers in a circular economy: the case of the built environment. In: Procedia CIRP, 26th CIRP Conference on Life Cycle Engineering (LCE) Purdue University, West Lafayette, IN, USA May 7-9, 2019 80, 619–624. Available from: https://doi.org/10.1016/j.procir.2018.12.015.

Høibye, L., Sand, H. (2018). *Circular Economy in the Nordic Construction Sector: Identification and assessment of potential policy instruments that can accelerate a transition toward a circular economy*. TEMANORD 2018, 517.

Hopkinson, P. *et al.* (2018) Recovery and reuse of structural products from end-of-life buildings, i *Proceedings of the Institution of Civil Engineers-Engineering Sustainability*. Thomas Telford Ltd, s. 119-128.

Ibenholt et al. (2020). Socio-economic analysis of reduced waste in the construction industry. Socio-economic analysis.Available from:https://dibk.no/globalassets/02.-om-oss/rapporter-ogpublikasjoner/samfunnsokonomisk-analyse-av-redusert-avfall-i-byggebransjen_nibio-ogsamfunnsokonomisk- analyse-2020.pdf.

Innovation Norway (2020). Good solutions for circular and sustainable buildings are sought!. Available from:https://www.innovasjonnorge.no/no/verktoy/mulighetsomrader/biookonomi/gode-losningerfor-sirkulare-og-barekraftige-bygg-sokes/. (Retrieved: May 15, 202).

IPCC (2018). *Global Warming of 1.5°C*. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. Available from: https://www.ipcc.ch/site/assets/uploads/sites/2/2019/05/SR15_SPM_version_report_LR.pdf

IRP (2017). International Resource Panel: *Assessing Global Resource Use- A Systems Approach to Resource Efficiency and Pollution Reduction*. Available from: https://www.resourcepanel.org/reports/assessing-global-resource-use

Jacobsen, D. (2015). How to conduct surveys? : Introduction to the social science method (3rd ed.). Oslo: Cappelen Damm academic.

Jensen, K. G. *et al.* (2019) *Building a Circular Future*. 3rd. edition. Copenhagen: published with support from the "Danish Environmental Protection Agency".

Available from: https://issuu.com/3xnarchitects/docs/building_a_circular_future_3__2_
Kilvær, L. et al. (2019). Proper reuse of building materials. dibk.no: Team Resirqel. Available from: https://dibk.no/globalassets/02.-om-oss/rapporter-og-publikasjoner/forsvarlig-ombruk-avbyggevarer_resirqel-2019.pdf (Retrieved: 12. March 2022).
Knoth, Katrin, Selamawit Mamo Fufa, and Erlend Seilskjær (2022). "Barriers, Success Factors, and Perspectives for the Reuse of Construction Products in Norway." Journal of Cleaner Production 337 (February): 130494. Available from: https://doi.org/10.1016/j.jclepro.2022.130494.
Kylili, A. & Fokaides, P. A. (2017). Policy trends for the sustainability assessment of construction materials: A review, *Sustainable Cities and Society*, 35, p. 280-288. Available from: https://www.sciencedirect.com/science/article/pii/S2210670717303773 (Retrieved: May 3, 2022).
Kynbråten, E. and Larsstuen, K. (2015). *Technical requirements for measures in existing buildings* .dibk.no: NKF Norwegian Municipal Technical Association. Available from: https://dibk.no/globalassets/eksisterende-bygg/veiledningsstoff/tekniske-krav-ved-tiltak-i-eksisterende-bygg_eksempelsamling_nkf.pdf
LOOP - Foundation for Source Sorting and Recycling (2018). *Waste hierarchy*. Available from: https://snl.no/avfallshierarki. (Retrieved: 26 March 2022).
Loopfront (2021). Loopfront: *a platform for reuse mapping, documentation, collaboration, logistics, and reporting*. https://www.loopfront.com/no/
Lotherington, P. B. (2018). *The EU Building Materials Regulation prevents reuse*. Available from: https://byggmesteren.as/2018/10/30/eus-byggevareforordning-hindrer-ombruk/ (Retrieved: Feb 15., 2019).
Luscuere, L. M. (2017). Materials Passports: Optimising value recovery from materials. *Proceedings of the Institution of Civil Engineers-Waste and Resource Management*. Thomas Telford Ltd, s. 25-28. Available from: https://www.bamb2020.eu/wp-content/uploads/2018/01/Luscuere_MaterialsPassportsOptimisingValueRecoveryFromMaterials.pdf.
Madaster (n.d.). Madaster: *a digital register for materials.* https://madaster.no/
McLaughlin, H. (2012). *Understanding social work research* (2nd ed.). London: Sage.
Melton, P. (2020). *Buildings that last: Design for adaptability, deconstruction and reuse*. AIA, The American Institute of Architects. Available from: https://content.aia.org/sites/default/files/2020-03/ADR-Guide-final_0.pdf. (Retrieved April 26, 2022).
Merrild, H., Guldager Jensen , K., & Sommer , J. (2016). *Building a Circular Future*. (1 ed.) GXN. Available from: http://issuu.com/3xnarchitects/docs/buildingacircularfuture/283?e=5740644/35968611. (Retrieved: Mar14,2022).
Ministry of Climate and Environment (2013). *The Framework Directive for Waste*. Available from: https://www.regjeringen.no/no/sub/eos-notatbasen/notatene/2006/apr/rammedirektivet-foravfall/id2432014/ (Retrieved: 19 April 2022).
Ministry of Climate and Environment (2021). National strategy for a green, circular economy. Ministry of Climate and Environment, Oslo.
Ministry of Climate and Environmental Protection (2019). *Norway's climate speech with the EU adopted*. Available from:https://www.regjeringen.no/no/aktuelt/norges-klimaavtale-med-eu-vedtatt/id2675266/
Ministry of Climate and Environmental Protection (2020a). *Climate change and Norwegian climate policy*. Available from: https://www.regjeringen.no/no/tema/klima-og-miljo/innsiktsartikler-klimamiljo/klimaendringer-og-norsk-klimapolitikk/id2636812/

Ministry of Climate and Environmental Protection (2020b). *National Strategy for Circular Economy*. Available from: https://www.regjeringen.no/contentassets/aa6878f3c539417092eeec88bac23f9b/1-4-kld.pdf

Minunno, R. *et al.* (2020). Exploring environmental benefits of reuse and recycle practices: A circular economy case study of a modular building, *Resources, Conservation and Recycling*, V. 160,2020, Article 104855. Available from: https://www.sciencedirect.com/science/article/pii/S0921344920301750.

Möhring, H. (2019) The country's first circular gypsum factory opens. Available from: https://avfallsbransjen.no/2019/08/15/landets-forste-sirkulaere-gipsfabrikk-apner/ (Retrieved: April 18, 2022).

Moum, A., Skaar, C. og Midthun, K. T. (2017). *Circular economy in tomorrow's construction industry*. Available from:https://sintef.brage.unit.no/sintef-xmlui/bitstream/handle/11250/2491795/SINTEF+Byggforsk+-+Sirkul%C3%A6r+%C3%B8konomi+i+morgendagens+byggen%C3%A6ring+%282017-0508%29.pdf?sequence=2.

Multiconsult & Building Environment (2008). *Guide to adaptability - An introduction to adaptability in construction projects and in construction and property management*. Available from: https://www.byggemiljo.no/wp-content/uploads/2014/12/TilpasningsdyktighetByggemilj%C3%B8veileder-04.11.08.pdf.

Myhre, K., Widenoja, E. and Kilvær, L. (2018). *Reuse of steel and associated building materials. Oslo: Norwegian Steel Association*. Available from: https://www.stalforbund.no/uploads/source/files/products/Ombruksrapporten_utgave_1.1.pdf. (Retrieved: Feb 2, 2022).

Mynors, M. E. T. and Moldekleiv, R. S. (2017) Reuse of building components and materials, Norwegian University of Life Sciences, Ås. Available from:http://hdl.handle.net/11250/2465488. (Retrieved Jan 15, 2022).

Mysen, M., Aronsen, E. and Johansen, B. S. (2014). *Reuse of ventilation ducts when upgrading to demand-controlled ventilation*, SINTEF Fag. Available from: https://sintef.brage.unit.no/sintef-xmlui/bitstream/handle/11250/2372900/SINTEF_Fag_15.pdf?sequence=3&isAllowed=y. (Retrieved: Mar. 12, 2022).

Naber, N. (2012). *Reuse of hollow-core slabs from office buildings to residential buildings*. Available from: http://resolver.tudelft.nl/uuid:a04416b7-e8c0-499d-81c7-48c51b5e7fda. (Retrieved April 23, 2022).

Nielsen, S. *et al.* (2014) *Nordic Built Component Reuse*. København: Vandkunsten. Available from: https://www.diva-portal.org/smash/get/diva2:1431214/FULLTEXT01.pdf. (Retrieved: Mar 12, 2022).

Nordby et al. (2021). *Experience report: Reuse in Kristian August gate 13*. Entra ASA, Rev.1, released 20.01.2021, Available from: https://www.entra.no/storage/uploads/article-documents/ka13-erfaringsrapport-ombruk-rev1-250120-kl-1211.pdf

Nordby, A. S. & Wærner, E. R. (2017). *How to plan for less waste - A guide to reducing waste generation in the construction industry*. Available from: https://byggalliansen.no/wpcontent/uploads/2018/07/NGBC_veileder_Hvordan-planlegge-for-mindre-avfall.pdf.

Nordby, A. S. (2009). *Salvageability of building materials: Reasons, criteria and consequences regarding the architectural design that facilitate reuse and recycling*. Norwegian University of Science and Technology, Faculty of Architecture.

Nordby, A. S. (2017). *Non-toxic building materials*. Now! Available from:https://www.futurebuilt.no/Blogg#!/Blogg/Giftfrie-byggevarer.-Naa

Nordby, A. S. (2018). *Circular theory and practice*. Available from: https://www.futurebuilt.no/Blogg#!/Blogg/Sirkulaer-teori-og-praksis. (Retrieved: April 29, 2022).
Nordby, A. S. (2019). *Barriers and opportunities to reuse of building materials in the Norwegian construction sector*. IOP Conf. Ser. Earth Environ. Sci. 225, 012061. Available from: https://doi.org/10.1088/1755-1315/225/1/012061.
Nordby, A. S. (2020). *FutureBuilt criteria for circular buildings*. FutureBuilt quality criteria, Version 2.0, Published 16.03.20. Available from: https://www.futurebuilt.no/FutureBuilt-kvalitetskriterier
Nordby, A. S. et al. (2009). *Criteria for salvageability: the reuse of bricks, Building Research & Information*, 37 (1), pp. 55-67.
Nordby, A. S., Solli, C. and Dahlstrøm, O. (2015). *Comprehensive environmental assessment of building materials. The Housing Bank*. Available from: http://biblioteket.husbanken.no/arkiv/dok/Komp/helhetlig%20miljovording%20av%20bygg ematerialer.pdf.
Norwegian Environment Agency (2019a). *Waste plan 2020-2025 - Status and plans for waste management, including waste prevention program*. Regjeringen.no: The Norwegian Environment Agency. Available from: https://www.regjeringen.no/contentassets/c6a9a384d90c4af18bfd8458f3167708/avfallsplan2020-2025.pdf. (Retrieved: 28 April 2020).
Norwegian Environment Agency (2019b). *Waste incineration with energy utilization*. Available from: https://miljostatus.miljodirektoratet.no/tema/avfall/avfallshandtering/avfallsforbrenning-medenergiutnyttelse/. (Retrieved: 26 April 2022).
Norwegian Environment Agency (2019c). *Landfilling of waste*. Available from: https://miljostatus.miljodirektoratet.no/tema/avfall/avfallshandtering/deponering-av-avfall/. (Retrieved: 26 April 2019).
Norwegian Environment Agency (2020) Climate rate support for climate measures. Available from: https://www.miljodirektoratet.no/klimasats. (Retrieved: 12 March 2022).
Norwegian Environment Agency (n.d.). *Candidate list in REACH (SVHC list).* Available from:https://www.miljodirektoratet.no/ansvarsomrader/kjemikalier/regelverk/reach/reachkandidatlista-svhc-lista/. (Retrieved: 20 April 2022).
Norwegian Real Estate (2019). *How to succeed with the sustainability goals?.* Available from: https://www.norskeiendom.org/hvordan-lykkes-med-fns-baerekraftsmal/ (Retrieved: Feb 14, 2022).
Nußholz, J. L., Rasmussen, F. N. and Milios, L. (2019). Circular building materials: Carbon saving potential and the role of business model innovation and public policy, *Resources, Conservation and Recycling*, 141, s. 308-316. Available from:https://www.sciencedirect.com/science/article/pii/S0921344918304099.
Nyland, E. and Apelseth, M. (2019). *"Developers' risk of ambiguities in the tender documents."* Published: 20 May 2019. Available from: https://www.estatenyheter.no/byggherres-risiko-for-uklarheter-i-konkurransegrunnlaget/247884 (Retrieved Mar 2, 2022).
Old Bricks (n.d.). *Past and future in every single brick*. Available from: http://gamlemursten.dk/. (Retrieved: April 22, 2022).
Pimentel, R., Brown, D. and Sansom, M. (2019). *Steel construction institute (SCI) P427 - Structural Steel Reuse: assessment, testing and design principles.*
Pollution Control Act (1981). *Act on protection against pollution and waste*. Available from:https://lovdata.no/dokument/NL/lov/1981-03-13-6?q=forurensnings (Retrieved: Mar 7, 2020).
Pollution Control Regulations (2004) Regulations on the limitation of pollution Lovdata. Available from: https://lovdata.no/dokument/SF/forskrift/2004-06-01-931?q=forurensningsforsk.

Ragn-Sells (n.d.).Ragn-Sells Group: *a total provider of services related to the collection and recycling of residual products and waste*. https://www.ragnsells.no/
Rahla et al., 2021. Selection criteria for building materials and components in line with the circular economy principles in the built environment—a review of current trends. Infrastructure 6, 49. Available from: https://doi.org/10.3390/infrastructures6040049.
Rakhshan et al. (2020). *Components reuse in the building sector – a systematic review*. Waste Manag. Res. 38, 347–370. Available from: https://doi.org/10.1177/0734242X20910463.
REBUS, 2020. REBUS - Reuse of Building materials - a USer perspective. Available from: https://www.sintef.no/projectweb/rebus/. (Retrieved: Feb 4, 2022)
Rehub (2021). Rehub: *A hub that connects supply and demand for the reuse of building materials - including necessary additional services.* https://www.rehub.no/.
RENAS et al. (2019). *Circular economy in the construction, civil engineering, and real estate industry.* Oslo. Available from: https://de312f73-4ba4-4a83-b0e6-01dc20f54c34.filesusr.com/ugd/8853d3_c545ae54430e403cb8e47d9f81459e18.pdf?index=true. (Retrieved: April 20, 2022).
Resirqel (2020a). *Resirqel AS and Ragn-Sells AS launch Reuse-bank in the construction industry.* Available from: http://www.resirqel.no/nyheter/2020/5/12/resirqel-as-og-ragn-sells-as-lansererombruksbank-i-byggebransjen (Retrieved: May 15, 2022).
Resirqel (2020b). *A summary of reuse and circular economy in the Norwegian construction sector, 2019*. Available from: http://www.resirqel.no/nyheter/2020/1/31/2019-en-oppsummering-rundt-ombruk-og-sirkulrkonomi-i-norsk-bygg-og-anleggssektor. (Retrieved: Feb 11, 2022)
Resirqel (n.d.). Resirqel: *a specialist environment with an interdisciplinary background in construction, architecture, and property*. Available from: http://www.resirqel.no/om-oss-1
Richter, K. (2002*). LCA – Reuse / Recycle*. COST Action E13, p. 167. Report on the State of the Art. European Commission, Directorate-General for Research and Innovation VOL 2. Publications Office. Available from: https://op.europa.eu/en/publication-detail/-/publication/6ec3f4a9-b753-4981-9fdb-23abf85fca7f/language-en (Retrieved: April 12, 2022).
Rienecker, L., Stray Jørgensen, P., Skov, S., & Landaas, W. (2013). *The good thesis: Handbook in thesis writing at university and college*. (2nd ed.). Bergen: Fagbokforl.
Rodahl, T. (2019). *Digital twins*. Available from: https://ikt.tekna.no/digitale-tvillinger/ (Retrieved: December 1, 2019).
Rognlien (2002) Report 1: Reuse in the construction industry - State of the art. Oslo: Statsbygg. Available from: https://www.yumpu.com/no/document/read/33125877/jenbruk-i-byggebransjen-state-ofart-statsbygg.
Rønning, A., Lyng, K.-A. and Vold, M. (2011). *Knowledge platform for calculating climate impact from buildings and building materials - Literature study*. (Report No. OR. 02.11). Available from: https://www.osti.gov/etdeweb/servlets/purl/22031328 (Retrieved: Mar25, 2022).
Rose, C. M., & Stegemann, J. A. (2018). Characterizing existing buildings as material banks (E-BAMB) to enable component reuse. *Proceedings of the Institution of Civil Engineers: Engineering Sustainability, 172*(3), p. 129–140. Available from: https://doi.org/10.1680/jensu.17.00074. (Retrieved May 5, 2022).
Sandberg et al. (2021). *Reuse of building materials - market, drivers and barriers*. Available from: https://sintef.brage.unit.no/sintef-xmlui/bitstream/handle/11250/2828094/SINTEF%2bNotat%2b%2b40.pdf.
Saunders, M. N. K., Lewis, P., and Thornhill, A. (2016). *Research methods for business students*. 7th ed. released. Harlow: Pearson.

Selvig, E. et al. (2020). *Low-emission materials in construction. Barriers and opportunities*. (NIBIO Report 8217025193). NIBIO-Ås. Available from: https://nibio.brage.unit.no/nibio-xmlui/bitstream/handle/11250/2651382/NIBIO_RAPPORT_2020_6_20.pdf (Retrieved May 2, 2022)

SINTEF Building Research (2004a). *700,307 Definitions, establishment and use of lifetime data for buildings and building components*. Available from: https://www.byggforsk.no/dokument/3208/definisjoner_etablering_og_bruk_av_levetidsdata__for_bygg_og_bygningsdeler (Retrieved: March 11, 2022).

SINTEF Building Research (2004b). *344.110 Adaptable office buildings.* Available from: https://www.byggforsk.no/dokument/3223/tilpasningsdyktige_kontorbygninger#i4 (Retrieved: April 14, 2022).

SINTEF Building Research (2011). *700,806 Execution of demolition work*. Available from: https://www.byggforsk.no/dokument/646/gjennomfoering_av_rivearbeider#i5. (Retrieved: Mar 5, 2022).

SINTEF Building Research (2012). *470,114 Building materials - suitability for material recycling*. Available from: https://www.byggforsk.no/dokument/4040/byggevarer_suitability_for_material recycling (Retrieved: Mar. 12, 2022).

SINTEF Building Research (2014a). *470.101 Life cycle assessment (LCA) of building materials and buildings. Introduction and concepts.* Available from: https://www.byggforsk.no/dokument/205/livsloepsvurder_lca_av_byggevarer_og_bygning er_innfoering_og_begreper # i12. (Retrieved: Mar. 12, 2022).

SINTEF Building Research (2014b). *470,103 Environmental declarations (EPD) of construction products*. Available from: https://www.byggforsk.no/dokument/3006/miljoedeklarasjoner_epd_av_byggevarer#i12. (Retrieved: Mar. 13, 2022).

SINTEF Building Research (2015). *470.102 Methodological choices and issues in life cycle assessment (LCA)*. Available from: https://www.byggforsk.no/dokument/4144/metodiske_valg_og_problemstillinger_ved_livsloe psvisning_lca. (Retrieved: Mar. 15, 2022).

SINTEF Building Research (2016). *570.001 Requirements for product documentation for sales and use of building materials*. Available from: https://www.byggforsk.no/dokument/565/krav_til_produktdokumentasjon_for_omsetning_og__bruk_av_byggevarer. (Retrieved: April 1, 2019).

SINTEF Building Research (2017a). *773,340 Asbestos in buildings. Occurrence and detection*. Available from: https://www.byggforsk.no/dokument/731/asbest_i_bygninger_forekomst_og_paavisning. (Retrieved: April 27, 2022).

SINTEF Building Research (2017b). *600.004 Building regulation. Concepts and definitions*. Available from: https://www.byggforsk.no/dokument/607/byggforvaltning_begreper_og_definisjoner#_52_O mbygging. (Retrieved: March22, 2022).

SINTEF Building Research (2017c). *700,320 Intervals for maintenance and replacement of building parts.* Available from: https://www.byggforsk.no/dokument/3312/intervaller_for_vedlikehold_og_utskiftinq_av_byg ningsdeler. (Retrieved: Mar. 11, 2022).

SINTEF Building Research (2018). *700,802 Environmental mapping and environmental remediation during demolition and conversion*. Available from: https://www.byggforsk.no/dokument/644/miljoekartlegging_og_miljoesanering_ved_riving_o g_ombygging # i3. (Retrieved: 29 April 2020).

SINTEF Certification (2020). *Environmental Product Declaration (EPD)*. Available from: https://www.sintefcertification.no/portalpage/index/184 (Retrieved: Mar. 4, 2022).

Sørnes, K. et al. (2014). *Recommendations for reuse of building materials*. Available from:https://www.sintefbok.no/book/index/985/anbefalinger_ved_ombruk_av_byggematerialer.

St. report 45 (2016-2017) (2017). *Waste as a resource- waste policy and circular economy*. Oslo: Ministry of Climate and the Environment. Available from: https://www.regjeringen.no/no/dokumenter/meld.-st.-45-20162017/id2558274/?q=Meld.%20St.%2045%20(2016-2017).(Retrieved: 24.04.2022).

Standard Norway (2006). *NS-EN ISO 14044: 2006*. *Environmental management - Life cycle assessment - Requirements and guidelines*. Available from: https://www.standard.no/no/Nettbutikk/produktkatalogen/Produktpresentasjon/?ProductID=23 6803.

Standard Norway (2011). *NS-EN 15978: 2011. Sustainability of construction works Assessment of the environmental performance of buildings Calculation method*. Available from:https://www.standard.no/en/PDF/FileDownload/?redir=true&filetype=Pdf&preview=true&item=600241&category=5

Standard Norway (2018). *Method for greenhouse gas calculations for buildings.* Available from:https://www.standard.no/en/PDF/FileDownload/?redir=true&filetype=Pdf&preview=true&item=992162&category=5

Statistics Norway (2020a). *The building stock*. Available from: https://www.ssb.no/bygningsmasse. (Retrieved: Mar. 17, 2022).

Statistics Norway (2020b). *Waste from construction activity*. Available from: https://www.ssb.no/avfbygganl (Retrieved: April 28, 2022).

Statistics Norway (2020c). *03173: Existing building stock. Buildings other than residential buildings, by type of building (F) 2001 - 2020*. Available from: https://www.ssb.no/statbank/table/03173/. (Retrieved: May 11, 2022).

Statistics Norway (2020d). *StatBank Denmark, Building area - 10785: Building area*. *Departure of buildings, by region, building type, statistical variable and year*. Available from:https://data.ssb.no/api/v0/no/table/10785/. (Retrieved: April 28, 2022).

Statistics Norway, 2021. *Waste from Building and Construction*. Available from: https://www.ssb.no/en/natur-og-miljo/statistikker/avfbygganl/aar/202 1-02-25. (Retrieved: Feb 8, 2022).

Steinmann, Z. J. et al. (2016). How many environmental impact indicators are needed in the evaluation of product life cycles?, *Environmental science & technology*, 50(7), s. 3913-3919.

Sunde, O. W. et al. (2019). *Instruments for increased reuse. Sandvika*.Available from: https://www.klimaoslo.no/wp-content/uploads/sites/88/2020/09/Virkemidler-for-okt-ombruk_AsplanViak.pdf. (Retrieved April 12, 2022).

The builder (2020). *Particleboard of recycled wood*. Available from: https://byggmesteren.as/2020/05/07/sponplater-av-resirkulert-trevirke/. (Retrieved: Mar. 18, 2022).

The Prime Minister's Office (2019). *The Granavolden platform. regjeringen.no.* Available from: https://www.regjeringen.no/no/dokumenter/politisk-plattform/id2626036/#klima. (Retrieved: Feb. 20, 2022).

Thormark, C. (2000). Environmental analysis of a building with reused building materials, *International Journal of Low Energy & Sustainable Building*, 1.

Tjora, A. (2021). *Qualitative research methods in practice*. (4th ed.). Oslo: Gyldendal.

UNEP (2019). *Emissions Gap Report 2019*. Available from: https://wedocs.unep.org/bitstream/handle/20.500.11822/30798/EGR19ESEN.pdf?sequence=1 3 (Retrieved: Feb. 11, 2022).

UNEP and IEA (2018). *Global Status Report- Towards a zero-emission, efficient and resilient buildings and construction sector*. Available from: https://wedocs.unep.org/bitstream/handle/20.500.11822/27140/Global_Status_2018.pdf?seque nce=1&isAllowed=y. (Retrieved: Feb 12, 2022).

UNEP and IEA (2019). *Global Status Report for Buildings and Construction.* Available from: https://www.unenvironment.org/resources/publication/2019-global-status-report-buildingsand-construction-sector (Retrieved: Feb 26, 2022).

UN-SDGs, (2019). *The United Nations' Sustainable Development Goals*. Available from: https://sdgs.un.org/goals. (Retrieved: Jan 13, 2022).
Valde, S., Ottesen, M. E. and Wormstrand, E. (2018). *Mapping of material flows from small and medium-sized construction, demolition and rehabilitation projects. Oslo. Available from*: https://www.byggemiljo.no/wp-content/uploads/2018/03/Kartlegging-av-byggavfall-fra-mindre-prosjekter_versjon-2.pdf (Retrieved: April 28, 2022)
Van den Berg, M., Voordijk, H. and Adriaanse, A. (2020). *Recovering building elements for reuse (or not)–Ethnographic insights into selective demolition practices,* Journal of cleaner production, 256, s. 120332.
Van Dijk, S., Tenpierik, M. and van den Dobbelsteen, A. (2014). Continuing the building's cycles: A literature review and analysis of current systems theories in comparison with the theory of Cradle to Cradle, *Resources, Conservation and Recycling*, 82, s. 21-34.
Wærner, E. R. (2020). *Waste reduction in the design phase.* Available from: https://www.byggemiljo.no/wp-content/uploads/2020/02/Avfallreduksjon-i-prosjekteringsfasen-rapport-workshop-281119.pdf. (Retrieved: May 3, 2022)
Waste Norway, VESAR and Norwegian Recycling (2016). *The waste and recycling industry's roadmap for the circular economy. Oslo*. Available from: https://s3-eu-west-1.amazonaws.com/avfall-norgeno/dokumenter/2016-XX-Avfalls-og-jendvinningsbransjens-veikart-for-en-sirkulaerokonomi.pdf?mtime=20171005152839. (Retrieved: May 2, 2022)
Weber Saint-Gobain (2019) Statements of Performance (DoP) and CE marking. Available from:https://www.weber-norge.no/service-tjenester/teknisk-informasjon/ytelseserklaeringer-dopog-ce-merking. (Retrieved: Feb 22, 2022).
Wikimedia commons (2014). *Kristian Augusts gate 23 existing building, Oslo city center (Tullinløkka).* Available from:https://commons.wikimedia.org/wiki/File:Kristian_Augusts_gate_23_rk_169445_IMG_0568.JPG
Wilsgaard, S. (2018) Europe has received a new waste directive. Available from: https://www.avfallnorge.no/bransjen/nyheter/europa-har-f%C3%A5tt-nye-avfallsdirektiv. (Retrieved: 6 April 2022).
Yin, R. (2018). *Case study research and applications: Design and methods* (Sixth ed.). Los Angeles, California: SAGE.

Appendices

Appendix 1: KA13 Basic Greenhous Gas Calculations for Materials/Products

1A. Reference building

1B. As-Built

Appendix 2: KA23 Basic Greenhous Gas Calculations for Materials/Products

2A. Reference building

2B. As-Built

Appendix 3: KA23 Reuse Assessment Note Document

Appendix 4: KA23 Reuse calculations

Appendix 1: KA13 Basic Greenhous Gas Calculations For Materials

Kristian August Gate 13 Greenhouse gas calculation report, Rev.1, released 28.10.2020, prepared by Asplan Viak AS is available under the attachments panel, I. (.pdf file).

I. Kristian August Gate 13 _Greenhouse gas calculation report_Rev.1.pdf

<u>1A. Reference building</u>

Material Category	Location	Building Part	Material	Amount	Unit	A1-A3 Kg CO2eq.	B4 Kg CO2eq.	Sum Kg CO2eq.
Steel and other metals	Existing	Groundworks & foundations	Steel core piles	408809.45	kg	517416.48	0.00	517416.48
Steel and other metals	Existing	Load-bearing system	Steel beam, L, U and I profile	819.00	kg	1703.52	0.00	1703.52
Steel and other metals	Existing	Load-bearing system	Steel beam, L, U and I profile	9368.00	kg	19485.44	0.00	19485.44
Steel and other metals	Existing	Load-bearing system	Steel beam hollow profile	3462.00	kg	12532.44	0.00	12532.44
Steel and other metals	Existing	Load-bearing system	Steel beam hollow profile	2945.00	kg	10660.90	0.00	10660.90
Steel and other metals	Existing	Roof	Corrugated steel plates 10kg / m²	1380.00	kg	3513.20	0.00	3513.20
Steel and other metals	Existing	Roof	Fittings, parapet, steel	7.81	m²	421.54	453.88	875.42
Steel and other metals	Existing	Roof	Corrugated steel plates 10kg / m²	1380.00	kg	3513.20	0.00	3513.20
Steel and other metals	New building	Groundworks & foundations	Steel core piles	75600.00	kg	93744.00	0.00	93744.00
Steel and other metals	New building	Load-bearing system	Steel beam, L, U and I profile	7480.00	kg	15558.40	0.00	15558.40
Steel and other metals	New building	Load-bearing system	Steel beam, L, U and I profile	2371.00	kg	4931.68	0.00	4931.68
Steel and other metals	New building	Load-bearing system	Steel beam hollow profile	2061.00	kg	7460.82	0.00	7460.82
Steel and other metals	New building	Load-bearing system	Steel beam hollow profile	21458.00	kg	77677.96	0.00	77677.96
Steel and other metals	New building	Stairs & Balconies	Steel stairs	2922.00	kg	7830.96	0.00	7830.96

Steel & other metals (Total)								**776904.42**
Glass	Existing	External walls	Glass facade	11.00	m²	1265.25	175.59	1440.84
Glass	Existing	External walls	Glass facade	15.00	m²	1725.34	1966.51	3691.85
Glass	Existing	Internal walls	Glass in office fronts	80.00	m²	7263.20	1948.53	9211.73
Glass	Existing	Internal walls	Glass panels	145.00	m²	13164.55	13822.78	26987.33
Glass	Existing	Roof	Skylight	13.51	m²	942.52	0.00	942.52
Glass (Total)								**42274.27**
Reinforced Concrete	Existing	Groundworks & foundations	Concrete, grout	43.00	m³	12196.28	0.00	12196.28
Reinforced Concrete	Existing	Load-bearing system	Concrete column	300.00	m³	99000.00	0.00	99000.00
Reinforced Concrete	Existing	External walls	Concrete wall, load-bearing	560.00	m³	201600.00	0.00	201600.00
Reinforced Concrete	Existing	Internal walls	Elevator shaft Concrete wall, load-bearing	278.00	m³	100080.00	0.00	100080.00
Reinforced Concrete	Existing	Roof	Concrete roof	267.30	m³	96228.00	0.00	96228.00
Reinforced Concrete	Existing	Stairs & Balconies	Concrete stairs	0.98	m³	342.21	0.00	342.21
Reinforced Concrete	Existing	Flooring	Hollow-core slabs	4780.00	m²	408015.83	0.00	408015.83
Reinforced Concrete	Existing	Flooring	Concrete, screed on hollow-core slabs	8.31	m³	1924.44	0.00	1924.44
Reinforced Concrete	Existing	Flooring	Cast-in-place slab	91.42	m³	25930.45	0.00	25930.45
Reinforced Concrete	Existing	Load-bearing system	Reinforcing steel for column	30450.00	kg	18879.00	0.00	18879.00
Reinforced Concrete	Existing	External walls	Reinforcing steel, for concrete wall	5684.00	kg	3524.08	0.00	3524.08
Reinforced Concrete	Existing	Internal walls	Reinforcing steel, for concrete wall	28217.00	kg	17494.54	0.00	17494.54
Reinforced Concrete	Existing	Flooring	Reinforcing steel, cast-in-place slab	5.50	kg	1.98	0.00	1.98
Reinforced Concrete	Existing	Roof	Reinforcing steel, for concrete roofs	27130.95	kg	16821.19	0.00	16821.19

Reinforced Concrete	New building	Groundworks & foundations	Concrete, grout	9.00	m³	2552.71	0.00	2552.71
Reinforced Concrete	New building	External walls	430mm concrete wall	16.77	m³	4756.55	0.00	4756.55
Reinforced Concrete	New building	Flooring	Concrete, screed on hollow-core slabs	12.92	m³	2990.36	0.00	2990.36
Reinforced Concrete	New building	Stairs & Balconies	concrete stairs	2.11	m³	736.80	0.00	736.80
Reinforced Concrete	New building	Flooring	Hollow-core slabs	160.00	m²	13657.43	0.00	13657.43
Reinforced Concrete	New building	Flooring	Hollow-core slabs	254.43	m²	21717.88	0.00	21717.88
Reinforced Concrete	New building	Roof	Hollow-core slab B45 / H40	80.22	m²	6847.49	0.00	6847.49
Reinforced Concrete	New building	Flooring	Leveling compound	1.58	m³	499.83	0.00	499.83
Reinforced Concrete	New building	External walls	Reinforcing steel, 200 kg / m³	3354.00	kg	1740.73	0.00	1740.73
Reinforced Concrete	New building	Flooring	Reinforcing steel, cast-in-place slab	883.93	kg	548.04	0.00	548.04
Reinforced Concrete (Total)								**1058085.82**
Doors	Existing	External walls	Exterior door, aluminum with glass	10.00	Pcs.	1830.00	0.00	1830.00
Doors	Existing	External walls	Exterior door, wood	1.00	Pcs.	96.20	70.26	166.46
Doors	Existing	Internal walls	Interior door, wood	32.00	Pcs.	2137.60	1337.92	3475.52
Doors	Existing	Internal walls	Interior door, wood with glass	8.00	Pcs.	448.00	377.34	825.34
Doors	Existing	Internal walls	Interior door, metal	14.00	Pcs.	296.80	771.19	1067.99
Doors	Existing	Internal walls	Interior door, aluminum with glass	25.00	Pcs.	4575.00	0.00	4575.00
Doors	New building	External walls	Exterior door aluminum	6.00	Pcs.	127.20	330.51	457.71
Doors	New building	Internal walls	Interior door, wood	4.00	Pcs.	267.20	0.00	267.20
Doors	New building	Internal walls	Interior door, wood with glass	2.00	Pcs.	112.00	94.34	206.34
Doors	New building	Internal walls	Interior door, aluminum with glass	6.00	Pcs.	1247.76	0.00	1247.76
Windows	Existing	External walls	Windows	231.83	m²	14914.09	15465.72	30379.81

Windows	New building	External walls	Window, two casements	87.00	m²	6979.12	0.00	6979.12
Windows	New building	External walls	Window, two casements	104.00	m²	8342.86	0.00	8342.86
Doors &Windows (Total)								**59821.11**
Gypsum board & studs	Existing	External walls	13 mm Gypsum/plaster	173.89	m²	295.61	201.97	497.58
Gypsum board & studs	Existing	External walls	15 mm fireproof gypsum	10.24	m²	26.62	17.38	44.00
Gypsum board & studs	Existing	External walls	9 mm GU-X boards	108.72	m²	184.82	0.00	184.82
Gypsum board & studs	Existing	Internal walls	13 mm gypsum/plaster	2099.20	m²	6066.69	0.00	6066.69
Gypsum board & studs	Existing	Internal walls	15 mm fireproof gypsum	485.71	m²	1262.85	0.00	1262.85
Gypsum board & studs	Existing	Internal walls	13 mm gypsum/plaster	750.88	m²	2170.04	0.00	2170.04
Gypsum board & studs	Existing	Internal walls	15 mm fireproof gypsum	62.04	m²	161.30	0.00	161.30
Gypsum board & studs	New building	External walls	standard gypsum, external walls	130.00	m²	375.70	151.00	526.70
Gypsum board & studs	New building	External walls	Fireproof gypsum, external walls	143.00	m²	371.80	242.67	614.47
Gypsum board & studs	New building	External walls	9 mm GU-X boards	2.45	m²	4.16	0.00	4.16
Gypsum board & studs	New building	External walls	Inside exterior walls with gypsum	272.00	m²	118.64	474.78	593.42
Gypsum board & studs	New building	Internal walls	13 mm gypsum/plaster	102.04	m²	294.90	118.52	413.42
Gypsum board & studs	New building	Internal walls	Interior walls with gypsum	37.80	m²	16.49	65.98	82.47
Gypsum board & studs	New building	Internal walls	70 mm studs	56.63	kg	52.13	0.00	52.13
Gypsum board & studs	Existing	External walls	70 mm studs	18.38	kg	16.92	0.00	16.92
Gypsum board & studs	Existing	Internal walls	70 mm studs	1662.78	kg	1530.47	0.00	1530.47
Gypsum board & studs	Existing	Internal walls	100 mm studs	329.56	kg	303.34	0.00	303.34

Gypsum board & studs	Existing	Internal walls	50 mm slotted steel studs	477.30	kg	439.32	0.00	439.32
Gypsum board & studs	Existing	Internal walls	70 mm studs	400.96	kg	369.05	0.00	369.05
Gypsum board & studs	Existing	Internal walls	100 mm studs	61.60	kg	56.70	0.00	56.70
Gypsum-board & studs (Total)								**15389.85**
Wood	Existing	Internal walls	200 mm TEWO (CLT)	88.67	m²	3449.13	0.00	3449.13
Wood	Existing	Internal walls	15 mm Veneer	450.00	m²	1036.80	0.00	1036.80
Wood	Existing	Internal walls	15 mm Veneer	275.54	m²	633.74	0.00	633.74
Wood	Existing	External walls	23+48 mm Lath	10.87	m³	576.22	0.00	576.22
Wood	Existing	Roof	Terrace floor, 28 mm	192.01	m²	1411.82	0.00	1411.82
Wood (Total)								**7107.71**
Façade cladding	Existing	External walls	Metal, fiber cement, & stone composite plates	223.78	m²	11352.36	6070.19	17422.55
Façade cladding	New building	External walls	Metal, fiber cement, & stone composite plates	472.22	m²	23955.72	12140.37	36096.09
Façade cladding (Total)								**53518.64**
Brick, Stone & ceramics	Existing	Internal walls	Ceramic tiles	80.00	m²	840.00	1597.62	2437.62
Brick, Stone & ceramics	Existing	Internal walls	Ceramic tiles glue	288.00	m²	721.46	1158.30	1879.76
Brick, Stone & ceramics	Existing	Internal walls	Ceramic tiles	106.00	m²	1113.00	870.29	1983.29
Brick, Stone & ceramics	Existing	Internal walls	Ceramic tiles glue	381.60	m²	955.93	1534.75	2490.68
Brick, Stone & ceramics	Existing	Flooring	Ceramic tiles, 5mm	87.50	m²	918.75	249.63	1168.38
Brick, Stone & ceramics	Existing	Flooring	Ceramic tiles glue	87.50	m²	219.19	0.00	219.19
Brick, Stone & ceramics	Existing	Roof	Roof tops	400.25	m²	2037.27	12177.53	14214.80
Brick, Stone & ceramics	New building	External walls	250 mm Brick	34.00	m³	13259.00	0.00	13259.00

Brick, Stone & ceramics	New building	Flooring	Brick, courtyard	8.84	m³	3447.34	0.00	3447.34
Brick, Stone & ceramics	New building	Roof	Stone, slate-tiled roof	1.70	m³	148.24	0.00	148.24
Brick, Stone & ceramics (Total)								**41248.30**
Insulation	Existing	External walls	48 mm Insulation	5.22	m³	112.20	0.00	112.20
Insulation	Existing	External walls	148 mm Insulation	28.27	m³	1636.57	0.00	1636.57
Insulation	Existing	External walls	98 mm Insulation	10.65	m³	351.60	0.00	351.60
Insulation	Existing	External walls	70 mm Insulation	0.04	m³	1.45	0.00	1.45
Insulation	Existing	Internal walls	70mm Insulation	11.32	m³	373.50	0.00	373.50
Insulation	Existing	Internal walls	100 mm Insulation	18.67	m³	616.21	0.00	616.21
Insulation	Existing	Internal walls	70 mm Insulation	7.56	m³	249.44	0.00	249.44
Insulation	Existing	Internal walls	100 mm Insulation	2.00	m³	66.01	0.00	66.01
Insulation	Existing	Roof	30 mm Fireproof insulation	4.15	m³	805.28	226.71	1031.99
Insulation	Existing	Roof	225 mm Insulation	31.11	m³	1801.28	0.00	1801.28
Insulation	Existing	Roof	30 mm Fireproof insulation	4.15	m³	805.28	226.71	1031.99
Insulation	Existing	Roof	Insulation 100 mm	131.67	m³	7623.00	0.00	7623.00
Insulation	Existing	Roof	Insulation TR 100 mm	131.67	m³	7623.00	0.00	7623.00
Insulation	New building	External walls	48 mm Insulation	13.06	m³	280.70	0.00	280.70
Insulation	New building	External walls	148 mm Insulation	13.06	m³	755.87	0.00	755.87
Insulation	New building	External walls	98 mm Insulation	26.66	m³	879.65	0.00	879.65
Insulation	New building	External walls	250 mm Isoblock	10.71	m²	542.10	0.00	542.10
Insulation	New building	External walls	250mm Anchor plate	34.00	m³	1530.00	0.00	1530.00
Insulation	New building	External walls	250mm Anchor plate	36.25	m³	1631.25	0.00	1631.25
Insulation	New building	External walls	250 mm Isoblock	36.00	m²	1821.46	0.00	1821.46
Insulation	New building	External walls	200mm Insulation	7.80	m³	451.58	0.00	451.58
Insulation	New building	Internal walls	70mm Insulation	1.82	m³	60.06	0.00	60.06
Insulation	New building	Internal walls	100 mm Insulation	1.20	m³	39.60	0.00	39.60
Insulation	New building	Flooring	Insulation 90 mm, pressure-resistant	12.83	m³	742.86	0.00	742.86

Insulation	New building	Flooring	Insulation 40 mm, pressure-resistant	5.70	m³	330.16	0.00	330.16
Insulation	New building	Roof	30 mm Fireproof insulation	1.47	m³	285.47	80.37	365.84
Insulation	New building	Roof	225 mm Insulation	11.03	m³	638.55	0.00	638.55
Insulation	New building	Roof	30 mm Fireproof insulation	1.47	m³	285.47	80.37	365.84
Insulation	New building	Roof	Insulation 90 mm	12.83	m³	742.86	0.00	742.86
Insulation	New building	Roof	Insulation 40 mm	5.70	m³	330.16	0.00	330.16
Insulation (Total)								**34026.78**
Ceiling panels	Existing	Flooring	Acoustic ceiling panels, 25 mm	4.75	m³	338.97	111.92	450.89
Ceiling panels	Existing	Flooring	Glass wool ceiling tiles, 50 mm	9.51	m³	845.21	0.00	845.21
Ceiling panels	Existing	Flooring	Acoustic ceiling panels, 25 mm	36.57	m³	2609.71	384.86	2994.57
Ceiling panels	Existing	Flooring	Glass wool ceiling tiles, 50 mm	73.14	m³	6500.38	0.00	6500.38
Ceiling panels	New building	Flooring	Acoustic ceiling panels, 25 mm	8.36	m³	596.57	196.84	793.41
Ceiling panels	New building	Flooring	Glass wool ceiling tiles, 50 mm	16.72	m³	1486.51	0.00	1486.51
Ceiling panels	New building	Flooring	Acoustic ceiling panels, 25 mm	1.36	m³	97.05	14.30	111.35
Ceiling panels	New building	Flooring	Glass wool ceiling tiles, 50 mm	2.72	m³	241.82	0.00	241.82
Ceiling panels (Total)								**13424.15**
Floor covering	Existing	Flooring	Wooden floor	41.69	m²	382.7142	779.72	1162.43
Floor covering	New building	Flooring	Wooden floor	45.42	m²	416.9556	424.74	841.6956
Floor covering	New building	Flooring	Wooden floor, oak	42.92	m²	394.0056	401.36	795.3656
Floor covering	Existing	Flooring	Carpet tile	1622.00	m²	21086	130327.70	151413.7
Floor covering	New building	Flooring	Carpet tile	541.00	m²	7033	43469.35	50502.35
Floor covering (Total)								**204715.55**

1B. As-Built

Material Category	Location	Building Part	Material	Amount	Unit	A1-A3, Kg CO2 eq.	B4 Kg CO2 eq.	Sum
Steel and other metals	Existing	Load-bearing system	Steel beam, L, U and I profile	819.00	kg	1012.12	0.00	1012.12
Steel and other metals	Existing	Load-bearing system	Steel beam, L, U and I profile, reuse	9368.00	kg	347.31	0.00	347.31
Steel and other metals	Existing	Load-bearing system	Steel beam hollow profile	3462.00	kg	8931.96	0.00	8931.96
Steel and other metals	Existing	Load-bearing system	Steel beam, hollow profile, reuse	2945.00	kg	235.89	0.00	235.89
Steel and other metals	Existing	Roof	Corrugated steel plates 10kg / m²	1380.00	kg	3513.20	0.00	3513.20
Steel and other metals	Existing	Roof	Fittings, parapet	7.81	m²	421.54	453.88	875.42
Steel and other metals	New building	Groundworks & foundations	Steel core piles	75600.00	kg	93744.00	0.00	93744.00
Steel and other metals	New building	Load-bearing system	Steel beam, L, U and I profile	7480.00	kg	9243.78	0.00	9243.78
Steel and other metals	New building	Load-bearing system	Steel beam, L, U and I profile, reuse	2371.00	kg	87.90	0.00	87.90
Steel and other metals	New building	Load-bearing system	Steel beam hollow profile	2061.00	kg	5317.38	0.00	5317.38
Steel and other metals	New building	Load-bearing system	Steel beam, hollow profile, reuse	21458.00	kg	1718.79	0.00	1718.79
Steel and other metals	New building	Stairs & Balconies	steel stairs	2922.00	kg	7830.96	0.00	7830.96
Steel & other metals (Total)								**132858.71**
Glass	Existing	External walls	Glass facade, reuse	11.00	m²	113.87	175.59	289.46
Glass	Existing	External walls	Glass facade	15.00	m²	1725.34	1966.51	3691.85
Glass	Existing	Internal walls	Glass in office fronts, reuse	80.00	m²	580.80	1948.53	2529.33
Glass	Existing	Internal walls	Glass panels	145.00	m²	13164.55	13822.78	26987.33

Glass (Total)								**33497.97**
Reinforced Concrete	Existing	Load-bearing system	Concrete column	0.31	m³	89.06	0.00	89.06
Reinforced Concrete	Existing	External walls	Concrete wall, load-bearing	96.24	m³	27297.00	0.00	27297.00
Reinforced Concrete	Existing	Flooring	Leveling compound	0.06	m³	17.40	0.00	17.40
Reinforced Concrete	Existing	Flooring	Concrete, Cast-in-place slab	91.42	m³	25930.45	0.00	25930.45
Reinforced Concrete	Existing	Stairs & Balconies	concrete stairs	0.98	m³	342.21	0.00	342.21
Reinforced Concrete	Existing	Load-bearing system	Reinforcing steel for column	31.40	kg	16.30	0.00	16.30
Reinforced Concrete	Existing	External walls	Reinforcing steel, for concrete wall	9624.00	kg	3464.64	0.00	3464.64
Reinforced Concrete	Existing	Flooring	Reinforcing steel, cast-in-place slab	5.50	kg	1.98	0.00	1.98
Reinforced Concrete	New building	Groundworks & foundations	Concrete, grout	9.00	m³	2552.71	0.00	2552.71
Reinforced Concrete	New building	External walls	430mm concrete wall	16.77	m³	4756.55	0.00	4756.55
Reinforced Concrete	Existing	Flooring	Concrete, screed on hollow-core slabs	8.31	m³	1924.44	0.00	1924.44
Reinforced Concrete	New building	Flooring	Hollow-core slabs, reused	127.83	m²	1200.27	0.00	1200.27
Reinforced Concrete	New building	Flooring	Hollow-core slabs	254.43	m²	21717.88	0.00	21717.88
Reinforced Concrete	New building	Roof	Hollow-core slab B45 / H40	80.22	m²	6847.49	0.00	6847.49
Reinforced Concrete	New building	Flooring	Concrete, screed on hollow-core slabs	12.92	m³	2990.36	0.00	2990.36
Reinforced Concrete	New building	Flooring	Leveling compound	1.58	m³	499.83	0.00	499.83
Reinforced Concrete	New building	Flooring	Concrete, Cast-in-place slab	4.57	m³	1295.08	0.00	1295.08
Reinforced Concrete	New building	Stairs & Balconies	concrete stairs	2.11	m³	736.80	0.00	736.80
Reinforced Concrete	New building	External walls	Reinforcing steel, 200 kg / m³	3354.00	kg	1740.73	0.00	1740.73

Reinforced Concrete	New building	Flooring	Reinforcing steel, cast-in-place slab	883.93	kg	318.22	0.00	318.22
Reinforced Concrete (Total)								**103739.4**
Doors	Existing	External walls	Exterior door, aluminum with glass	10.00	Pcs.	1830.00	0.00	1830.00
Doors	Existing	External walls	Exterior door, wood	1.00	Pcs.	96.20	70.26	166.46
Doors	Existing	Internal walls	Interior door, wood, reuse	32.00	Pcs.	304.00	190.27	494.27
Doors	Existing	Internal walls	Interior door, wood with glass	8.00	Pcs.	448.00	377.34	825.34
Doors	Existing	Internal walls	Interior door, metal	14.00	Pcs.	296.80	771.19	1067.99
Doors	Existing	Internal walls	Interior door, aluminum with glass, reuse	25.00	Pcs.	366.00	0.00	366.00
Doors	New building	External walls	Exterior door aluminum	6.00	Pcs.	127.20	330.51	457.71
Doors	New building	Internal walls	Interior door, wood	4.00	Pcs.	267.20	0.00	267.20
Doors	New building	Internal walls	Interior door, wood with glass	2.00	Pcs.	112.00	94.34	206.34
Doors	New building	Internal walls	Interior door, aluminum, with glass	6.00	Pcs.	1247.76	0.00	1247.76
Windows	Existing	External walls	Windows	231.83	m²	14914.09	15465.72	30379.81
Windows	New building	External walls	Window, two casements, 30 pcs., reuse	87.00	m²	628.12	0.00	628.12
Windows	New building	External walls	Window, two casements	104.00	m²	8342.86	0.00	8342.86
Doors & Windows (Total)								**46279.86**
Gypsum-board & studs	Existing	External walls	13 mm Gypsum/plaster	173.89	m²	295.61	201.97	497.58
Gypsum-board & studs	Existing	External walls	15 mm Fireproof gypsum	10.24	m²	26.62	17.38	44.00
Gypsum-board & studs	Existing	External walls	9 mm GU-X boards	108.72	m²	184.82	0.00	184.82
Gypsum-board & studs	Existing	Internal walls	13mm Gypsum/plaster	2099.20	m²	3568.64	0.00	3568.64
Gypsum-board & studs	Existing	Internal walls	15 mm Fireproof gypsum	485.71	m²	1262.85	0.00	1262.85
Gypsum-board & studs	Existing	Internal walls	13 mm Gypsum, reuse	750.88	m²	255.30	0.00	255.30

Gypsum-board & studs	Existing	Internal walls	15 mm Firproof gypsum, reuse	62.04	m²	32.26	0.00	32.26
Gypsum-board & studs	New building	External walls	standard gypsum external walls	130.00	m²	221.00	151.00	372.00
Gypsum-board & studs	New building	External walls	Fireproof gypsum, external walls	143.00	m²	371.80	242.67	614.47
Gypsum-board & studs	New building	External walls	9 mm GU-x boards	2.45	m²	4.16	0.00	4.16
Gypsum-board & studs	New building	External walls	Inside exterior walls with plaster	272.00	m²	118.64	474.78	593.42
Gypsum-board & studs	New building	Internal walls	13mm Gypsum/plaster	102.04	m²	173.47	118.52	291.99
Gypsum-board & studs	New building	Internal walls	Interior walls with plaster	37.80	m²	16.49	65.98	82.47
Gypsum-board & studs	New building	Internal walls	70 mm studs	56.63	kg	52.13	0.00	52.13
Gypsum-board & studs	Existing	External walls	70 mm studs	18.38	kg	16.92	0.00	16.92
Gypsum-board & studs	Existing	Internal walls	70 mm studs	1662.78	kg	1530.47	0.00	1530.47
Gypsum-board & studs	Existing	Internal walls	100mm studs	329.56	kg	303.34	0.00	303.34
Gypsum-board & studs	Existing	Internal walls	50 mm slotted steel studs	477.30	kg	439.32	0.00	439.32
Gypsum-board & studs	Existing	Internal walls	70 mm studs, reuse	400.96	kg	73.81	0.00	73.81
Gypsum-board & studs	Existing	Internal walls	100 mm studs, reuse	61.60	kg	11.34	0.00	11.34
Gypsum-board & studs (Total)								**10231.29**
Wood	Existing	Internal walls	200 mm TEWO (CLT)	88.67	m²	3449.13	0.00	3449.13
Wood	Existing	Internal walls	15 mm Veneer	450.00	m²	1036.80	0.00	1036.80
Wood	Existing	Internal walls	15 mm Veneer, ombruk	275.54	m²	126.75	0.00	126.75
Wood	Existing	Roof	Terrace floor, 28 mm	192.01	m²	1411.82	0.00	1411.82
Wood	Existing	External walls	23+48 mm Lath	10.87	m³	576.22	0.00	576.22
Wood (Total)								**6600.72**

Façade cladding	Existing	External walls	Facade panels, reuse	223.78	m²	354.59	6070.19	6424.78
Façade cladding	New building	External walls	Facade panels, reuse	472.22	m²	1723.00	12140.37	13863.37
Façade cladding (Total)								**20288.15**
Brick, Stone & ceramics	Existing	Internal walls	Ceramic tiles	80.00	m²	840.00	1597.62	2437.62
Brick, Stone & ceramics	Existing	Internal walls	Ceramic tiels glue	288.00	m²	721.46	1158.30	1879.76
Brick, Stone & ceramics	Existing	Internal walls	Ceramic tiels, reuse	106.00	m²	222.60	870.29	1092.89
Brick, Stone & ceramics	Existing	Internal walls	Ceramic tiels glue	381.60	m²	955.93	1534.75	2490.68
Brick, Stone & ceramics	Existing	Flooring	Ceramic tiels, 5 mm	87.50	m²	918.75	249.63	1168.38
Brick, Stone & ceramics	Existing	Flooring	Ceramic tiels glue	87.50	m²	219.19	0.00	219.19
Brick, Stone & ceramics	Existing	Roof	Roof tops/Roofing	400.25	m²	2037.27	12177.53	14214.80
Brick, Stone & ceramics	New building	External walls	250 mm Brick, reuse	34.00	m³	2652.00	0.00	2652.00
Brick, Stone & ceramics	New building	Flooring	Brick, courtyard	8.84	m³	3447.34	0.00	3447.34
Brick, Stone & ceramics	New building	Roof	Stone, slate-tiled roof, reuse	1.70	m³	53.46	0.00	53.46
Brick, Stone & ceramics (Total)								**29656.12**
Insulation	Existing	External walls	48 mm Insulation	5.22	m³	112.20	0.00	112.20
Insulation	Existing	External walls	148 mm Insulation	28.27	m³	1636.57	0.00	1636.57
Insulation	Existing	External walls	98 mm Insulation	10.65	m³	351.60	0.00	351.60
Insulation	Existing	External walls	70 mm Insulation	0.04	m³	1.45	0.00	1.45
Insulation	Existing	Internal walls	70mm Insulation	11.32	m³	373.50	0.00	373.50
Insulation	Existing	Internal walls	100 mm Insulation	18.67	m³	616.21	0.00	616.21
Insulation	Existing	Internal walls	70 mm Insulation, reuse	7.56	m³	49.90	0.00	49.90
Insulation	Existing	Internal walls	100 mm Insulation, reuse	2.00	m³	13.20	0.00	13.20
Insulation	Existing	Roof	30 mm Fireproof insulation	4.15	m³	805.28	226.71	1031.99

Insulation	Existing	Roof	225 mm Insulation	31.11	m³	1801.28	0.00	1801.28
Insulation	Existing	Roof	30 mm Fireproof insulation	4.15	m³	805.28	226.71	1031.99
Insulation	Existing	Roof	Insulation 100 mm	131.67	m³	7623.00	0.00	7623.00
Insulation	Existing	Roof	Insulation TR 100 mm	131.67	m³	7623.00	0.00	7623.00
Insulation	New building	External walls	48 mm Insulation	13.06	m³	280.70	0.00	280.70
Insulation	New building	External walls	148 mm Insulation	13.06	m³	755.87	0.00	755.87
Insulation	New building	External walls	98 mm Insulation	26.66	m³	879.65	0.00	879.65
Insulation	New building	External walls	250 mm Isoblock	10.71	m²	542.10	0.00	542.10
Insulation	New building	External walls	250mm Anchor plate, reuse	34.00	m³	306.00	0.00	306.00
Insulation	New building	External walls	250mm Anchor plate	36.25	m³	1631.25	0.00	1631.25
Insulation	New building	External walls	300mm Isoblock	36.00	m²	1821.46	0.00	1821.46
Insulation	New building	External walls	200mm Insulation	7.80	m³	451.58	0.00	451.58
Insulation	New building	Internal walls	70mm Insulation	1.82	m³	60.06	0.00	60.06
Insulation	New building	Internal walls	100 mm Insulation	1.20	m³	39.60	0.00	39.60
Insulation	New building	Flooring	Insulation 90 mm, pressure-resistant	12.83	m³	742.86	0.00	742.86
Insulation	New building	Flooring	Insulation 40 mm, pressure-resistant	5.70	m³	330.16	0.00	330.16
Insulation	New building	Roof	30 mm Fireproof Insulation	1.47	m³	285.47	80.37	365.84
Insulation	New building	Roof	225 mm Insulation	11.03	m³	638.55	0.00	638.55
Insulation	New building	Roof	30 mm Fireproof Insulation	1.47	m³	285.47	80.37	365.84
Insulation	New building	Roof	Insulation 90 mm	12.83	m³	742.86	0.00	742.86
Insulation	New building	Roof	Insulation 40 mm	5.70	m³	330.16	0.00	330.16
Insulation (Total)								**32550.43**
Ceiling panels	Existing	Flooring	Acoustic ceiling panels, 25 mm	4.75	m³	338.97	111.92	450.89
Ceiling panels	Existing	Flooring	Glass wool ceiling tiles, 50 mm	9.51	m³	845.21	0.00	845.21
Ceiling panels	Existing	Flooring	Acoustic ceiling panels, 25 mm, reuse	36.57	m³	443.37	384.86	828.23
Ceiling panels	Existing	Flooring	Glass wool ceiling tiles, 50 mm, reuse	73.14	m³	1105.51	0.00	1105.51

Ceiling panels	New building	Flooring	Acoustic ceiling panels, 25 mm	8.36	m³	596.57	196.84	793.41
Ceiling panels	New building	Flooring	Glass wool ceiling tiles, 50 mm	16.72	m³	1486.51	0.00	1486.51
Ceiling panels	New building	Flooring	Acoustic ceiling panels, 25 mm, reuse	1.36	m³	16.49	14.30	30.79
Ceiling panels	New building	Flooring	Glass wool ceiling tiles, 50 mm, reuse	2.72	m³	41.10	0.00	41.10
Ceiling panels (Total)								**5581.65**
Floor covering	Existing	Flooring	Wooden floor	41.69	m²	9.1718	779.72	788.89
Floor covering	New building	Flooring	Wooden floor	45.42	m²	9.9924	424.74	434.7324
Floor covering	New building	Flooring	Wooden floor, oak	42.92	m²	9.4424	401.36	410.8024
Floor covering	Existing	Flooring	Carpet tile, reuse	1622.00	m²	1686.88	130327.70	132014.6
Floor covering	New building	Flooring	Carpet tile, reuse	541.00	m²	562.64	43469.35	44031.99
Floor covering (Total)								**177681**

Appendix 2: KA23 Basic Greenhous Gas Calculations for Materials

Kristian August Gate 23 Greenhouse gas calculation report, Rev.2, released 04.03.2022, prepared by Multiconsult AS is available under the attachments panel, II. (pdf file).

II. Kristian August Gate 23 _Greenhouse gas calculation report_ Rev.2.pdf

2A. Reference building

Material Category	Location	Building Part	Material	Amount	Unit	A1-A3, Kg CO2 eq.	B4 Kg CO2 eq.	Sum
Steel and other metals	Existing	Groundworks & found.	Structural steel profiles, generic, 60% recycled content, I, H, U, L, and T sections.	228226.00	kg	473920.01	0.00	473920.01
Steel and other metals	Existing	External walls	Aluminum profile, 2700.0 kg / m³	0.29	m3	1569.26	0.00	1569.26
Steel and other metals	Existing	Internal walls	Structural steel profiles, generic, 60% recycled content, I, H, U, L, and T sections.	1640.00	kg	3405.52	0.00	3405.52
Steel and other metals	Existing	Internal walls	Structural steel profiles, generic, 60% recycled content, I, H, U, L, and T sections.	3608.17	kg	7492.50	0.00	7492.50
Steel and other metals	Existing	Roof	Aluminum profile, 2700.0 kg / m³	0.71	m3	3804.91	0.00	3804.91
Steel and other metals	Existing	Roof	Steel plates, generic, 90% recycled content.	32.75	m2	276.02	0.00	276.02
Steel and other metals	New building	Load-bearing system	Structural hollow steel profiles, cold-rolled, generic, 10% recycled content.	0.02	m3	652.82	0.00	652.82
Steel and other metals	New building	Load-bearing system	Structural hollow steel profiles, cold-rolled, generic, 10% recycled content.	1769.00	kg	6396.26	0.00	6396.26

Steel and other metals	New building	Load-bearing system	Structural steel profiles, generic, 60% recycled content, I, H, U, L, and T sections.	2800.00	kg	5814.31	0.00	5814.31
Steel and other metals	New building	Internal walls	Structural steel profiles, generic, 60% recycled content, I, H, U, L, and T sections.	0.02	m3	342.32	0.00	342.32
Steel and other metals	New building	Stairs & Balconies	Hot-dip galvanized steel sheets, recommended sheet thickness range: 0.4-3.0 mm, zinc coating: 20 μm.	0.17	m3	3651.77	0.00	3651.77
Steel & other metals (Total)								**507325.7**
Glass	Existing	External walls	Curtain wall with steel frame, 54.64kg / m², Uw <2.8W / m².K	1491.30	m2	204622.51	0.00	204622.51
Glass	Existing	Roof	Fire-resistant glass, 21.1 mm and 50.5 kg.m², 2393 kg/m³.	2.46	m3	7669.42	7749.11	15418.53
Glass	New building	External walls	Curtain wall with steel frame, 54.64kg / m², Uw <2.8W / m².K	88.04	m2	12080.04	0.00	12080.04
Glass (Total)								**232121.08**
Reinforced Concrete	Existing	Groundworks & found.	Reinforced concrete, normal strength, generic, B20 (var: low carbon class C), C20 / 25	150031	kg	13156.89	0.00	13156.89
Reinforced Concrete	Existing	Load-bearing system	Concrete columns, B35 M45 / MF45, low carbon class B	0.28	m3	78.68	0.00	78.68
Reinforced Concrete	Existing	Load-bearing system	Concrete columns, B35 M45 / MF45, low carbon class B.	0.58	m3	161.84	0.00	161.84
Reinforced Concrete	Existing	Load-bearing system	Concrete columns, B35 M45 / MF45, low carbon class B.	1.01	m3	282.80	0.00	282.80
Reinforced Concrete	Existing	Load-bearing system	Concrete columns, B35 M45 / MF45, low carbon class B.	1.46	m3	408.80	0.00	408.80

Reinforced Concrete	Existing	Load-bearing system	Concrete columns, B35 M45 / MF45, low carbon class B.	1.52	m3	425.60	0.00	425.60
Reinforced Concrete	Existing	Load-bearing system	Concrete columns, B35 M45 / MF45, low carbon class B.	2.78	m3	778.40	0.00	778.40
Reinforced Concrete	Existing	Load-bearing system	Concrete columns, B35 M45 / MF45, low carbon class B.	3.51	m3	982.80	0.00	982.80
Reinforced Concrete	Existing	Load-bearing system	Concrete columns, B35 M45 / MF45, low carbon class B.	4.77	m3	1335.60	0.00	1335.60
Reinforced Concrete	Existing	Load-bearing system	Concrete columns, B35 M45 / MF45, low carbon class B.	6.12	m3	1713.60	0.00	1713.60
Reinforced Concrete	Existing	Load-bearing system	Concrete columns, B35 M45 / MF45, low carbon class B.	17.53	m3	4908.40	0.00	4908.40
Reinforced Concrete	Existing	Load-bearing system	Concrete columns, B35 M45 / MF45, low carbon class B.	20.33	m3	5692.40	0.00	5692.40
Reinforced Concrete	Existing	Load-bearing system	Concrete columns, B35 M45 / MF45, low carbon class B.	35.95	m3	10066.00	0.00	10066.00
Reinforced Concrete	Existing	Load-bearing system	Concrete columns, B35 M45 / MF45, low carbon class B.	39.86	m3	11160.80	0.00	11160.80
Reinforced Concrete	Existing	Load-bearing system	Reinforcement steel to columns, generic, 97% recycled content, A615.	13569.90	kg	6111.82	0.00	6111.82
Reinforced Concrete	Existing	Load-bearing system	Concrete beams, B35 M45 / MF45, low carbon class B.	0.45	m3	126.00	0.00	126.00
Reinforced Concrete	Existing	Load-bearing system	Concrete beams, B35 M45 / MF45, low carbon class B.	0.76	m3	211.40	0.00	211.40
Reinforced Concrete	Existing	Load-bearing system	Concrete beams, B35 M45 / MF45, low carbon class B.	14.84	m3	4155.20	0.00	4155.20
Reinforced Concrete	Existing	Load-bearing system	Concrete beams, B35 M45 / MF45, low carbon class B.	46.31	m3	12966.80	0.00	12966.80
Reinforced Concrete	Existing	Load-bearing system	Concrete beams, B35 M45 / MF45, low carbon class B.	93.72	m3	26241.60	0.00	26241.60
Reinforced Concrete	Existing	Load-bearing system	Reinforcement steel to beams, generic, 97% recycled content, A615.	15607.50	kg	7029.55	0.00	7029.55
Reinforced Concrete	Existing	External walls	Lightweight clinker blocks, LECA, generic, 650 kg / m³, 18 kg / block, 0.5x0.3x0.185 mm.	0.74	m3	24.27	0.00	24.27

Reinforced Concrete	Existing	External walls	Concrete wall, bearing, B35 M45 / MF45, low carbon class B.	707.08	m3	197982.40	0.00	197982.40
Reinforced Concrete	Existing	External walls	Reinforcement steel to walls, generic, 97% recycled content, A615.	70708.12	kg	31846.62	0.00	31846.62
Reinforced Concrete	Existing	Flooring	Concrete slabs, B35 M45 / MF45, low carbon class B.	1.14	m3	319.20	0.00	319.20
Reinforced Concrete	Existing	Flooring	Concrete slabs, B35 M45 / MF45, low carbon class B.	1.51	m3	422.80	0.00	422.80
Reinforced Concrete	Existing	Flooring	Concrete slabs, B35 M45 / MF45, low carbon class B.	2.34	m3	655.20	0.00	655.20
Reinforced Concrete	Existing	Flooring	Concrete slabs, B35 M45 / MF45, low carbon class B.	6.24	m3	1747.20	0.00	1747.20
Reinforced Concrete	Existing	Flooring	Concrete slabs, B35 M45 / MF45, low carbon class B.	7.87	m3	2203.60	0.00	2203.60
Reinforced Concrete	Existing	Flooring	Hollow-core slabs Type HD, W45 M45, 265x1200 mm, 8 rebars / m2, 371 kg / m2, HD 265.	10.51	m3	1686.67	0.00	1686.67
Reinforced Concrete	Existing	Flooring	Concrete slabs, B35 M45 / MF45, low carbon class B.	11.17	m3	3127.60	0.00	3127.60
Reinforced Concrete	Existing	Flooring	Dry mortar, fiber-reinforced, cement- and lime-based, weber.base 261 Fiber plaster.	29.80	m3	12609.87	0.00	12609.87
Reinforced Concrete	Existing	Flooring	Hollow-core slabs Type HD, W45 M45, 265x1200 mm, 8 rebars / m2, 371 kg / m2, HD 265.	177.42	m3	28472.72	0.00	28472.72
Reinforced Concrete	Existing	Flooring	Leveling compound, cement-based, 10-100 mm	194.79	m3	66618.18	0.00	66618.18
Reinforced Concrete	Existing	Flooring	Concrete slabs, B35 M45 / MF45, low carbon class B.	301.60	m3	84448.00	0.00	84448.00
Reinforced Concrete	Existing	Flooring	Concrete slabs, B35 M45 / MF45, low carbon class B.	975.48	m3	273134.40	0.00	273134.40

Reinforced Concrete	Existing	Flooring	Reinforcement steel to slabs, generic, 97% recycled content, A615.	147888.50	kg	66608.31	0.00	66608.31
Reinforced Concrete	Existing	Roof	Reinforced concrete, normal strength, generic, B45 (var: low carbon class C), C40 / 50.	172.00	m2	12495.20	0.00	12495.20
Reinforced Concrete	Existing	Roof	Reinforced concrete, normal strength, generic, B45 (var: low carbon class C), C40 / 50.	229.00	m2	16636.05	0.00	16636.05
Reinforced Concrete	Existing	Roof	Reinforcement steel to roof slab, generic, 90% recycled content, A615	4962.00	kg	3093.96	0.00	3093.96
Reinforced Concrete	Existing	Roof	Reinforcement steel to roof slab, generic, 90% recycled content, A615	6595.20	kg	4112.31	0.00	4112.31
Reinforced Concrete	Existing	Stairs & Balconies	Concrete, B35 M45 / MF45, low carbon class B.	0.30	m3	83.16	0.00	83.16
Reinforced Concrete	Existing	Stairs & Balconies	Concrete, B35 M45 / MF45, low carbon class B.	1.09	m3	305.20	0.00	305.20
Reinforced Concrete	Existing	Stairs & Balconies	Stairs, Nor Element stairs	1.09	m3	393.81	0.00	393.81
Reinforced Concrete	Existing	Stairs & Balconies	Concrete, B35 M45 / MF45, low carbon class B.	1.33	m3	372.40	0.00	372.40
Reinforced Concrete	Existing	Stairs & Balconies	Concrete, B35 M45 / MF45, low carbon class B.	2.92	m3	817.60	0.00	817.60
Reinforced Concrete	Existing	Stairs & Balconies	Concrete, B35 M45 / MF45, low carbon class B.	19.50	m3	5460.00	0.00	5460.00
Reinforced Concrete	Existing	Stairs & Balconies	Concrete, B35 M45 / MF45, low carbon class B.	37.55	m3	10514.00	0.00	10514.00
Reinforced Concrete	Existing	Stairs & Balconies	Reinforcement steel, generic, 97% recycled content, A615.	6263.70	kg	2821.14	0.00	2821.14
Reinforced Concrete	New building	External walls	Prefabricated concrete wall elements, generic, B30, C30 / 37.	0.23	m3	71.23	0.00	71.23

Reinforced Concrete	New building	External walls	Lightweight clinker blocks, LECA, generic, 650 kg / m³, 18 kg / block, 0.5x0.3x0.185 mm.	4.25	m3	138.65	0.00	138.65
Reinforced Concrete	New building	External walls	Lightweight clinker blocks, LECA, generic, 650 kg / m³, 18 kg / block, 0.5x0.3x0.185 mm.	17.83	m3	581.67	0.00	581.67
Reinforced Concrete	New building	External walls	Lightweight clinker blocks, LECA, generic, 650 kg / m³, 18 kg / block, 0.5x0.3x0.185 mm.	21.69	m3	707.59	0.00	707.59
Reinforced Concrete	New building	External walls	Finishing wall mortars, French average, 3 mm, 4.2 kg/m2.	175.97	m2	440.50	0.00	440.50
Reinforced Concrete	New building	External walls	Masonry block Multi 12, 187 x 187 x 387mm (H x W x L), 12.9 kg / unit, Multi 12.	994.90	kg	74.76	0.00	74.76
Reinforced Concrete	New building	Flooring	Concrete slabs, B35 M45 / MF45, low carbon class B.	6.07	m3	1699.60	0.00	1699.60
Reinforced Concrete	New building	Flooring	Concrete slabs, B35 M45 / MF45, low carbon class B.	10.06	m3	2816.80	0.00	2816.80
Reinforced Concrete	New building	Flooring	Concrete slabs, B35 M45 / MF45, low carbon class B.	47.95	m3	13426.00	0.00	13426.00
Reinforced Concrete	New building	Flooring	Reinforcement steel to slabs, generic, 97% recycled content, A615.	6408.00	kg	2886.13	0.00	2886.13
Reinforced Concrete (Total)								**959849.78**
Doors	Existing	External walls	Balcony door with aluminium cladding, 0.78 W/m²K, 69.73 kg, 1.23x1.48 m	4.26	m2	290.74	0.00	290.74
Doors	Existing	External walls	Sectional door, 21.74 kg/m2	15.01	m2	1445.53	1447.42	2892.95
Doors	Existing	External walls	Multifunctional steel door, product group 1, 1000mm x 2125 mm, H 3 D, H 3 OD, H	22.94	m2	1893.34	0.00	1893.34

			3 VM, H 3 KT, RS 55, D 65 OD, D 65					
Doors	Existing	External walls	Multifunctional steel door, product group 1, 1000mm x 2125 mm, H 3 D, H 3 OD, H 3 VM, H 3 KT, RS 55, D 65 OD, D 65	55.01	m2	4540.23	4554.07	9094.30
Doors	Existing	Internal walls	Interior glazed door with wooden frame, 1.96 x 2.09 m, 44.47 kg/m2, fire-resistance class.	7.33	m2	1071.46	1076.62	2148.08
Doors	Existing	Internal walls	Interior glazed door with wooden frame, 1.96 x 2.09 m, 44.47 kg/m², fire-resistance class.	17.60	m2	2572.67	2585.06	5157.73
Doors	Existing	Internal walls	Interior glazed door with wooden frame, 1.96 x 2.09 m, 44.47 kg/m2, fire-resistance class.	29.31	m2	4284.37	0.00	4284.37
Doors	Existing	Internal walls	Interior door, 809x2053 mm, 42x92 mm frame, 52 mm door leaf	30.33	m2	1022.64	0.00	1022.64
Doors	Existing	Internal walls	Climate door, 809x2053 mm, 42x92 mm frame, 52 mm door leaf.	247.59	m2	14340.71	0.00	14340.71
Doors	Existing	Internal walls	Interior glazed door with wooden frame, 1.96 x 2.09 m, 44.47 kg/m², fire-resistance class.	304.17	m2	44461.87	44676.06	89137.93
Doors	New building	Internal walls	Climate door, 809x2053 mm, 42x92 mm frame, 52 mm door leaf.	6.37	m2	368.96	401.00	769.96
Windows	Existing	External walls	Northwest window, fixed-frame window with aluminum cladding, 708 W / m²K, 66.54 kg, 1.23x1.48 m.	112.80	m2	7869.48	0.00	7869.48

Windows	Existing	External walls	Northwest window Fixed frame window with aluminum cladding, 708 W / m2K, 66.54 kg, 1.23x1.48 m	806.43	m2	56260.50	0.00	56260.50
Doors & Windows (Total)								**195162.73**
Gypsum-board & studs	Existing	External walls	Gypsum board, ordinary, generic, 6.5-25 mm, 10,725 kg / m², 858 kg / m³.	0.01	m3	1.78	0.00	1.78
Gypsum-board & studs	Existing	External walls	Gypsum board, ordinary, generic, 6.5-25 mm, 10,725 kg / m², 858 kg / m³.	0.02	m3	4.00	0.00	4.00
Gypsum-board & studs	Existing	External walls	Gypsum board, ordinary, generic, 6.5-25 mm, 10,725 kg / m², 858 kg / m³.	13.74	m3	3052.49	0.00	3052.49
Gypsum-board & studs	Existing	External walls	Gypsum board, ordinary, generic, 6.5-25 mm, 10,725 kg / m², 858 kg / m³.	14.94	m3	3319.08	0.00	3319.08
Gypsum-board & studs	Existing	Internal Walls	Gypsum board, ordinary, generic, 6.5-25 mm, 10,725 kg / m², 858 kg / m³.	0.20	m3	44.43	0.00	44.43
Gypsum-board & studs	Existing	Internal Walls	Gypsum board, ordinary, generic, 6.5-25 mm, 10,725 kg / m², 858 kg / m³.	58.00	m3	12885.31	0.00	12885.31
Gypsum-board & studs	Existing	Internal Walls	Gypsum board, ordinary, generic, 6.5-25 mm, 10,725 kg / m², 858 kg / m³.	800.00	m2	2310.47	0.00	2310.47
Gypsum-board & studs	Existing	Internal Walls	Gypsum board, ordinary, generic, 6.5-25 mm,	800.00	m2	2310.47	0.00	2310.47

			10,725 kg / m², 858 kg / m³.					
Gypsum-board & studs	Existing	Internal Walls	Gypsum board, ordinary, generic, 6.5-25 mm, 10,725 kg / m², 858 kg / m³.	1304.00	m2	3766.07	0.00	3766.07
Gypsum-board & studs	Existing	Internal Walls	Gypsum board, ordinary, generic, 6.5-25 mm, 10,725 kg / m², 858 kg / m³.	1304.00	m2	3766.07	0.00	3766.07
Gypsum-board & studs	Existing	Flooring	Gypsum board, ordinary, generic, 6.5-25 mm, 10,725 kg / m², 858 kg / m³.	45.48	m3	10103.86	0.00	10103.86
Gypsum-board & studs	New building	Internal Walls	Gypsum board, ordinary, generic, 6.5-25 mm, 10,725 kg / m², 858 kg / m³.	0.03	m3	7.55	0.00	7.55
Gypsum-board & studs	New building	Internal Walls	Gypsum board, ordinary, generic, 6.5-25 mm, 10,725 kg / m², 858 kg / m³.	0.10	m3	21.33	0.00	21.33
Gypsum-board & studs	New building	Internal Walls	Gypsum board, ordinary, generic, 6.5-25 mm, 10,725 kg / m², 858 kg / m³.	0.11	m3	23.55	0.00	23.55
Gypsum-board & studs	New building	Internal Walls	Gypsum board, ordinary, generic, 6.5-25 mm, 10,725 kg / m², 858 kg / m³.	0.37	m3	83.09	0.00	83.09
Gypsum-board & studs	New building	Internal Walls	Gypsum board, ordinary, generic, 6.5-25 mm, 10,725 kg / m², 858 kg / m³.	0.41	m3	91.97	0.00	91.97
Gypsum-board & studs	New building	Internal Walls	Gypsum board, ordinary, generic, 6.5-25 mm, 10,725 kg / m², 858 kg / m³.	0.75	m3	166.84	0.00	166.84

Gypsum board & studs (Total)								**41958.36**
Wood	Existing	External walls	Plywood from beech, generic, 4-50 mm, 620 kg / m³.	0.01	m3	0.37	0.00	0.37
Wood	Existing	External walls	Plywood from beech, generic, 4-50 mm, 620 kg / m³.	16.03	m3	857.84	0.00	857.84
Wood	Existing	External walls	Timber-frame system for external walls per sqm (incl. Air gaps per m3), 48x98 mm, 600 mm spacing	29.58	m3	75.25	0.00	75.25
Wood	Existing	Flooring	Wood cladding, pine, biochemical impregnation.	4.76	m3	1217.61	0.00	1217.61
Wood	Existing	Flooring	Solid hardwood floors, 600 kg / m3, 21x120mm, moist. 8%.	8.49	m3	1631.89	0.00	1631.89
Wood	Existing	Flooring	Cross laminated timber floor (CLT/XLAM), 470.88 kg/m3.	168.63	m3	14057.31	0.00	14057.31
Wood	New building	Internal walls	Plywood from beech, generic, 4-50 mm, 620 kg / m³.	0.20	m3	10.86	0.00	10.86
Wood	New building	Flooring	Wood cladding, pine, biochemical impregnation.	3.60	m3	920.88	0.00	920.88
Wood (Total)								**18772.01**
Façade cladding	Existing	External walls	Stoneware tiles glazed, 10 mm, 20.0 kg/m2, 2000 kg/m³	0.01	m3	0.61	0.69	1.30
Façade cladding	Existing	External walls	Natural stone quartzite slate, even thickness with sawn edges, 12 mm, 2700 kg / m³	1244.80	m2	8169.82	0.00	8169.82
Façade cladding	Existing	External walls	Stoneware tiles glazed, 10 mm, 20.0 kg/m², 2000 kg/m³	6.71	m3	585.16	657.76	1242.92

Façade cladding (Total)								**9414.04**
Brick, Stone & ceramics	Existing	External walls	Stoneware tiles glazed, 10 mm, 20.0 kg/m², 2000 kg/m3	0.01	m3	0.61	0.69	1.30
Brick, Stone & ceramics	Existing	External walls	Natural stone quartzite slate, even thickness with sawn edges, 12 mm, 2700 kg / m³	1244.80	m2	8169.82	0.00	8169.82
Brick, Stone & ceramics	Existing	Internal walls	Stoneware tiles glazed, 10 mm, 20.0 kg/m², 2000 kg/m3	6.71	m3	585.16	657.76	1242.92
Brick, Stone & ceramics	Existing	Flooring	Concrete paint, 1.2 kg / l, 37% solids / volume, 8-10 m² / l.	5.12	m3	17555.25	0.00	17555.25
Brick, Stone & ceramics	Existing	Flooring	Terrazzo quartz products, with cristobalite and mirror glass inserts, 125 x 125 or 60 x 60 cm, 20 mm, 50 kg/m².	6.18	m3	6834.78	0.00	6834.78
Brick, Stone & ceramics	Existing	Flooring	Terrazzo quartz products, with cristobalite and mirror glass inserts, 125 x 125 or 60 x 60 cm, 20 mm, 50 kg/m².	12.08	m3	13359.89	0.00	13359.89
Brick, Stone & ceramics (Total)								**47163.96**
Insulation	Existing	External walls	Insulation, glass wool / mineral wool, 17 kg / m³	291.96	m2	307.39	0.00	307.39
Insulation	Existing	External walls	Insulation, glass wool / mineral wool, 17 kg / m³	707.08	m3	14889.08	0.00	14889.08
Insulation	Existing	Internal walls	Glass wool insulation boards, generic, L = 0.031 W / mK, R = 3.23 m2K / W, 25 kg / m3, applicable for densities: 0-25 kg / m3, Lambda = 0.031 W / (m.K).	800.00	m2	256.33	0.00	256.33

Insulation	Existing	Internal walls	Glass wool insulation boards, generic, L = 0.031 W / mK, R = 3.23 m2K / W, 25 kg / m3, applicable for densities: 0-25 kg / m3, Lambda = 0.031 W / (m.K).	1304.00	m2	567.03	0.00	567.03
Insulation	Existing	Flooring	Insulation, glass wool / mineral wool, 17 kg / m³	141.60	m2	149.08	0.00	149.08
Insulation	Existing	Roof	Insulation, glass wool / mineral wool, 17 kg / m³	35.75	m2	75.28	0.00	75.28
Insulation	Existing	Roof	EPS insulation, T: 10-2400 mm, 600 x 1200 mm, 0.031 W / m2K, 16 kg / m³	43.00	m2	915.48	0.00	915.48
Insulation	Existing	Roof	EPS insulation, T: 10-2400 mm, 600 x 1200 mm, 0.031 W / m2K, 16 kg / m³	57.25	m2	1218.87	0.00	1218.87
Insulation	Existing	Roof	Glass wool insulation boards, generic, L = 0.031 W / mK, R = 3.23 m2K / W, 25 kg / m3, applicable for densities: 0-25 kg / m3, Lambda = 0.031 W / (m.K).	129.00	m2	177.14	0.00	177.14
Insulation	Existing	Roof	Glass wool insulation boards, generic, L = 0.031 W / mK, R = 3.23 m2K / W, 25 kg / m3, applicable for densities: 0-25 kg / m3, Lambda = 0.031 W / (m.K).	171.75	m2	235.84	0.00	235.84
Insulation	New building	Internal walls	Insulation, glass wool / mineral wool, 17 kg / m³	0.31	m3	6.61	0.00	6.61
Insulation	New building	Internal walls	Insulation, glass wool / mineral wool, 17 kg / m³	0.43	m3	8.95	0.00	8.95
Insulation	New building	Internal walls	Insulation, glass wool / mineral wool, 17 kg / m³	1.11	m3	23.37	0.00	23.37
Insulation	New building	Internal walls	Insulation, glass wool / mineral wool, 17 kg / m³	1.60	m3	33.69	0.00	33.69
Insulation	New building	Internal walls	Insulation, glass wool / mineral wool, 17 kg / m³	2.50	m3	52.64	0.00	52.64

Insulation	New building	Flooring	XPS insulation board, 33 mm, 300KPa, 0.033 - 0.039 W / mK, 1185x585.	4.04	m3	452.97	0.00	452.97
Insulation	New building	Flooring	Insulation, glass wool / mineral wool, 17 kg / m³	6.37	m3	134.13	0.00	134.13
Insulation	New building	Roof	Insulation, glass wool / mineral wool, 17 kg / m³	0.17	m3	3.50	0.00	3.50
Insulation	New building	Roof	Insulation, glass wool / mineral wool, 17 kg / m³	0.38	m3	7.98	0.00	7.98
Insulation	New building	Roof	Insulation, glass wool / mineral wool, 17 kg / m³	0.50	m3	10.44	0.00	10.44
Insulation	New building	Roof	Insulation, glass wool / mineral wool, 17 kg / m³	0.60	m3	12.57	0.00	12.57
Insulation	New building	Roof	Insulation, glass wool / mineral wool, 17 kg / m³	1.77	m3	37.27	0.00	37.27
Insulation	New building	Roof	Insulation, glass wool / mineral wool, 17 kg / m³	20.70	m3	435.88	0.00	435.88
Insulation (Total)								**20011.52**
Ceiling panels	Existing	Flooring	Ceiling wooden wool cement boards, white, 25, 50, 70, 100 and 150 mm, for wall systems: 400mm and 600mm, 400 kg / m³	0.08	m3	23.12	0.00	23.12
Ceiling panels	New building	Roof	Gypsum boards, ordinary, generic, 6.5-25 mm, 10,725 kg / m², 858 kg / m³	0.11	m3	25.10	0.00	25.10
Ceiling panels	New building	Roof	Gypsum boards, ordinary, generic, 6.5-25 mm, 10,725 kg / m², 858 kg / m³	0.15	m3	33.99	0.00	33.99
Ceiling panels	New building	Roof	Ceiling wooden wool cement boards, white, 25, 50, 70, 100 and 150 mm, for wall systems: 400mm and 600mm, 400 kg / m³	12.70	m3	3537.49	0.00	3537.49

Ceiling panels (Total)								**3619.70**
Floor covering	Existing	Flooring	Linoleum flooring, 2.25 mm, 2.9 kg/m2 (ERFMI)	0.09	m3	16.33	21.69	38.02
Floor covering	Existing	Flooring	Woven vinyl flooring, rolls, 5 mm, 2.94kg/m², up to 3 kg/m²	0.19	m3	179.82	902.92	1082.74
Floor covering	Existing	Flooring	Woven vinyl flooring, rolls, 5 mm, 2.94kg/m², up to 3 kg/m²	18.90	m3	18272.52	91748.29	110020.81
Floor covering	New building	Flooring	Woven vinyl flooring, rolls, 5 mm, 2.94kg/m², up to 3 kg/m²	6.00	m2	29.00	58.25	87.25
Floor covering	New building	Flooring	Tufted broadloom carpet, 3.26 kg/m2, polyamide 6.6, max. pile weight 1500 g/m2	198.83	m2	3280.70	14761.94	18042.64
Floor covering (Total)								**129271.46**

<u>2B. As-Built</u>

Material Category	Location	Building Part	Material	Amount	Unit	A1-A3, Kg CO2 eq.	B4 Kg CO2 eq.	Sum
Steel and other metals	New building	Load-bearing system	Structural hollow steel column profiles , S420MH, S355J2 double grade steel	5200.00	kg	12818.44	0.00	12818.44
Steel and other metals	New building	Load-bearing system	Structural steel beam profiles, generic, 60% recycled content, I, H, U, L, and T sections.	5750.00	kg	11940.09	0.00	11940.09
Steel and other metals	New building	Internal walls	Structural steel profiles, generic, 60% recycled content, I, H, U, L, and T sections.	0.70	m³	11410.58	0.00	11410.58
Steel and other metals	New building+ Existing	External walls	Hot-dip galvanized steel sheets, recommended	3360.00	kg	9194.42	0.00	9194.42

			sheet steel thickness range: 0.4-3.0 mm, zinc coating: 20 µm.					
Steel and other metals	New building	Stairs & Balconies	Hot-dip galvanized steel sheets, recommended sheet thickness range: 0.4-3.0 mm, zinc coating: 20 µm.	1.00	m^3	21481.02	0.00	21481.02
Steel and other metals	New building	Stairs & Balconies	Hot-dip galvanized steel sheets, recommended sheet thickness range: 0.4-3.0 mm, zinc coating: 20 µm.	0.17	m^3	3651.77	0.00	3651.77
Steel & other metals (Total)								**70496.32**
Glass	New building	External walls	Curtain wall with steel frame, 54.64kg/m^2, Uw<2.8W/m2.K.	26.40	m^2	3622.14	0.00	3622.14
Glass	New building	External walls	Curtain wall with steel frame, 54.64kg/m^2, Uw<2.8W/m2.K.	25.13	m^2	3447.89	0.00	3447.89
Glass	New building	External walls	Curtain wall with steel frame, 54.64kg/m^2, Uw<2.8W/m2.K.	88.04	m^2	12079.27	0.00	12079.27
Glass	New building	Roof	Curtain wall with steel frame, 54.64kg/m^2, Uw<2.8W/m2.K.	108.23	m^2	14849.38	0.00	14849.38
Glass (Total)								**33998.68**
Rein. Concrete	New building	External walls	Lightweight clinker blocks, LECA, generic, 650 kg / m^3, 18 kg / block, 0.5x0.3x0.185 mm.	0.23	m^3	7.55	0.00	7.55
Rein. Concrete	New building	External walls	Lightweight clinker blocks, LECA, generic, 650 kg / m^3, 18 kg / block, 0.5x0.3x0.185 mm.	0.99	m^3	32.07	0.00	32.07
Rein. Concrete	New building	External walls	Lightweight clinker blocks, LECA, generic, 650 kg /	4.25	m^3	137.68	0.00	137.68

			m³, 18 kg / block, 0.5x0.3x0.185 mm.					
Rein. Concrete	New building	External walls	Lightweight clinker blocks, LECA, generic, 650 kg / m³, 18 kg / block, 0.5x0.3x0.185 mm.	10.13	m³	328.17	0.00	328.17
Rein. Concrete	New building	External walls	Lightweight clinker blocks, LECA, generic, 650 kg / m³, 18 kg / block, 0.5x0.3x0.185 mm.	17.83	m³	577.62	0.00	577.62
Rein. Concrete	New building	External walls	Lightweight clinker blocks, LECA, generic, 650 kg / m³, 18 kg / block, 0.5x0.3x0.185 mm.	21.69	m³	702.67	0.00	702.67
Rein. Concrete	New building	Flooring	B30 M60 - UN53A-B000 Low Carbon, C30 / 37 (B30 M60), UN53A-B000.	47.95	m³	11005.00	0.00	11005.00
Rein. Concrete	New building	Flooring	Reinforcement steel, generic, 97% recycled content, A615	3500.00	kg	1576.38	0.00	1576.38
Rein. Concrete (Total)								**14367.14**
Doors	New building+ Existing	Internal walls	Climate door, 809x2053 mm, 42x92 mm frame, 52 mm door leaf	3000.00	kg	4508.67	4900.18	9408.85
Windows	New building+ Existing	Internal walls	System wall (windows), Partition system, 12.8 mm, element 2400 x 900 mm, door opening 2100 x 900 mm, full system 2400 x 2700 mm	17076.00	kg	102298.37	0.00	102298.37
Doors & Windows (Total)								**111707.22**
Gypsum board & studs	New building	Internal walls	Gypsum board, plain, generic, 6.5-25 mm, 10,725 kg / m², 858 kg / m³	38.80	m³	8619.83	0.00	8619.83
Gypsum board & studs	New building	Internal walls	Gipsfiberplate, 12.5 mm, 1180 kg/m3 (Fermacell)	39.16	m³	1339.04	0.00	1339.04

Gypsum board & studs (Total)								**9958.87**
Wood	New building	Internal walls	Plywood from beech, generic, 4-50 mm, 620 kg / m³	1.19	m³	63.68	0.00	63.68
Wood	New building	Internal walls	Oriented beach boards (OSB), generic, 9.5-28.5 mm, 610 kg / m3, min. G4-2	24.70	m³	885.15	0.00	885.15
Wood	New building+Existing	Flooring	Wood for outdoor use, planed softwood, copper impregnated, pigmented	5.60	m³	996.24	0.00	996.24
Wood	New building	Internal walls	Massive wooden flooring/parquet, 22-450 x 44-7000 x 8-35 mm, 11.71 kg/m²	784.00	m²	5354.07	6644.32	11998.39
Wood (Total)								**13943.46**
Façade cladding (Total)								**0.00**
Brick, Stone & ceramics	New building	Internal walls	Stoneware tiles glazed, 10 mm, 20.0 kg/m², 2000 kg/m³	30.00	m²	25.36	27.18	52.54
Brick, Stone & ceramics	New building	Flooring	Terrazzo quartz products, with cristobalite and mirror glass inserts, 125 x 125 or 60 x 60 cm, 20 mm, 50 kg/m²	780.00	m²	10752.06	10963.04	21715.10
Brick, Stone & ceramic (Total)								**21767.64**
Insulation	New building	Internal walls	Rockwool thermal insulation, L = 0.036 W/mK, R = 2.77 m2K/W, 100 mm, 11 kg/m2, 110 kg/m3.	199.36	m³	8851.58	0.00	8851.58
Insulation	New building	Flooring	Rockwool thermal insulation, L = 0.036 W/mK, R = 2.77 m2K/W,	39.66	m³	1760.90	0.00	1760.90

			100 mm, 11 kg/m2, 110 kg/m3.					
Insulation	New building	Roof	Rockwool thermal insulation, L = 0.036 W/mK, R = 2.77 m2K/W, 100 mm, 11 kg/m2, 110 kg/m3.	27.68	m³	1228.99	0.00	1228.99
Insulation (Total)								**11841.47**
Ceiling panels (Total)								**0.00**
Floor covering	New building	Flooring	Linoleum flooring, 2.25 mm, 2.9 kg/m2 (ERFMI)	95.00	m²	40.13	106.59	146.72
Floor covering	New building	Flooring	Terrazzo quartz products, with cristobalite and mirror glass inserts, 125 x 125 or 60 x 60 cm, 20 mm, 50 kg/m2	780.00	m²	10752.06	10963.04	21715.10
Floor covering	New building+ Existing	Flooring	Tufted carpet tiles, 3.00 kg/m2, pile material of polyamide (PA) 6, Ege Tuft 650 ECT350 Highline Loop ECT350	1156.00	m²	6623.88	20056.30	26680.18
Floor covering (Total)								**48542.00**

Appendix 3: KA23 Reuse Assessment Note Document

Kristian August Gate 23 reuse assessment note, Rev.0, released 16.12.2019, prepared by Multiconsult Norway AS can be accessed under the attachments panel, III. (pdf file).

III. Kristian Augusts gate 23_ Reuse assessment note _ phase 2_Rev.0.pdf

Appendix 4: KA23 Reuse calculations

The weight percentage of material/product (%)to the total weight of the building (of total %).

	Concrete	LECA (Siporex)	Window/ glass	Natural stone quartzite slate (solvågstein)	Steel	Gypsum	Fixed fixtures (partitions, ceiling tiles)	Kitchen	Brick	Ceramic tiles	Stairs	Elevator	Total
	kg												
Reuse	9,540,778	812,942	34.72	144,251.9	8,560	Recycled				3,000	10,000	1,200	10,520,766
Reuse on other projects (sold)							4,257	3,890	324,340				332,487
Not reused / recycled			Contained environmental toxins. Sanitized										1,497,000
Total weight:													**12,350,253**
The proportion of reused materials	88%												
Not reused	12%												