Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Architecture and Design
Department of Architecture and Technology

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Reuse of materials in the Norwegian building sector

Connecting embodied emissions with targeted reuse of building materials and components

Master's thesis in Sustainable Architecture
Supervisor: Michael Gruner
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Preface

This thesis marks the completion of my Master's degree in Sustainable Architecture at the Norwegian University of Science and Technology (NTNU). The project lasted from January 2022 until July 2022.

I would like to thank my supervisor, assistant professor at the Department of Architecture and Technology at NTNU, Michael Gruner, for support, guidance and inspiration during my work with this thesis.

I would also like to thank Torger Mjønes in Trøndelag Fylkeskommune, for connecting me with the project of Cissi Klein High School as well as the project team from Veidekke. Being allowed into their project, I have gotten invaluable insight into how it is to plan for reuse in today's building sector. It is one thing reading about reuse and a whole other thing seeing the work and collaborations between professionals in order to achieve environmental goals in projects. During the early-planning meetings I realized how complex today's system is in order to reuse materials, and the time and expertise needed. The Cissi Klein project gave me motivation and direction for creating something that might be useful for future projects.

Theodora Sideridis

Trondheim, 29.07.2022

Abstract

Norway needs to move towards becoming a more circular economy in order to mitigate climate change and meet the international sustainability targets. The building sector in Norway stands for a large amount of both material emissions and waste production, where reuse is seen as one of the strategies for lowering this industry's impact on emissions and raw material consumption.

The goal of this thesis is to give an in-depth understanding of reuse of building materials in Norway today, present qualitative descriptions and examples and develop planning tools to help and inspire for more reuse in the future. The thesis has aimed to gather all the different factors that affect the amount of reuse realized in today's construction sector. This includes considering waste materials, laws and regulations, looking at two different building certifications (FutureBuilt and BREEAM) and accounting for reuse in LCA calculations. Two project examples with goals for reuse are also presented and discussed (KA23 and Cissi Klein High School).

The result part presents three main tools to assist with planning for reuse.

- Find: looking at the connection between embodied emissions per building element and reuse. The solution examples highlight some materials and components that, when reused, have a larger contribution in lowering the material emissions.
- Plan: a flowchart that is developed to collect the different factors and aspects that need to be considered when planning for reuse in a project.
- Document: an excel table that can be used to document reused materials that are available in order to review and assess them.

The field of reuse of building materials is still in early development and changes both in the industry and regulations are happening. Having targets for reuse in a project today often entails added planning, cost and expertise needed from the entrepreneur firm and generally entails added work and complexity to the planning phase. Therefore, it is seen as useful to review and assess materials and components that when reused, have a larger contribution in lowering the material emissions early in the project planning.

The findings of the report also indicate the need for more services and companies that specialize in reused building materials. If there are more finished "products" that are reused in the market, it would be easier for projects to achieve higher rates of reuse.

Sammendrag

Norge må bevege seg mot å bli en mer sirkulær økonomi for å dempe klimaendringene og oppfylle de internasjonale bærekraftsmålene. Byggebransjen i Norge står for en stor mengde av både utslipp fra materialer og avfallsproduksjon, hvor gjenbruk ses på som en av strategiene for å redusere denne næringens påvirkning på utslipp og råvareforbruk.

Målet med denne oppgaven er å gi en helhetlig forståelse innen temaet gjenbruk av byggematerialer i Norge i dag, presentere kvalitative beskrivelser og eksempler og utvikle planleggingsverktøy for å hjelpe og inspirere til økt gjenbruk i fremtiden. Oppgaven har som mål å samle alle de ulike faktorene som påvirker mengden gjenbruk som realiseres i dagens byggebransje. Dette inkluderer å se på avfallsmaterialer, lover og forskrifter, se på to forskjellige bygningssertifiseringer (FutureBuilt og BREEAM) og redegjøre for gjenbruk i LCA-beregninger. To prosjekteksempler med mål for gjenbruk er også presentert og diskutert (KA23 og Cissi Klein videregående skole).

Resultatdelen presenterer tre hovedverktøy for å hjelpe til med planlegging for gjenbruk.

- Finne: Resultatdelen av oppgaven ser på sammenhengen mellom utslipp knyttet til materialbruk per bygningselement og gjenbruk.
- Planlegge: Et flytskjema er utviklet for å samle de ulike faktorene og aspektene som må vurderes ved planlegging for gjenbruk i et prosjekt.
- Dokumentere: en Excel-tabell som kan brukes til å dokumentere tilgjengelige ombrukt materiale som er tilgjengelig for å gjennomgå og vurdere det.

Ombruksfeltet for byggematerialer ligger fortsatt i en tidlig utvikling og det kommer stadig endringer både i bransjen og innenfor regelverk. Å ha mål for gjenbruk i et prosjekt i dag innebærer ofte økt planlegging, kostnader og kompetanse som trengs fra entreprenørfirmaet og påfører generelt mer arbeid og kompleksitet til planleggingsfasen. Derfor sees det som nyttig å gjennomgå og vurdere materialer og komponenter som ved gjenbruk har et større bidrag til å redusere materialutslippene tidlig i prosjektplanleggingen.

Funnene i rapporten indikerer også at det er behov for flere tjenester og bedrifter som spesialiserer seg på ombrukte byggematerialer. Hvis det er flere ferdige «produkter» som gjenbrukes i markedet, vil det være lettere for prosjekter å oppnå høyere grad av ombruk.

Table of contents

List of figures

List of tables

Vocabulary

Reuse	Something being used more than once for its intended purpose
Recycling	Collection of products for separation into their base materials, which can then replace raw materials in the production process.
Downcycling	Recycling for a purpose with lower performance requirements than the original
GHG	Greenhouse gas
Emissions	In the context of this thesis, “emissions” is used to mean greenhouse gas emissions, which is a quantification of mass of CO2 equivalents, measured in kgCO2e
Embodied emissions	Embodied emissions do not depend on the occupants of the building. The energy consumed is built into the materials and it largely depends on the type of material used, primary energy sources, and efficiency of conversion processes in making the building materials and products.
Operational emissions	Operational emissions are directly related to the building occupants and their pattern of energy usage. It accumulates over time and can be influenced throughout the life of the building.
Service life	Expected or actual lifetime of a component or a building, may be confined by functional, technical, economic or esthetic reasons.
LCA	Life Cycle Assessment
NS	Norwegian Standard

1. Introduction

1.1 Background

The building industry stands for 40% of greenhouse gas (GHG) emissions globally. Our planet is increasingly getting warmer due to these emissions, and a big responsibility therefore lies with this industry for reducing the impact on our planet. Most countries acknowledge climate change and see the need to act to prevent the earth from losing its balance. In light of this, the United Nations has created a list of goals that aim towards sustainable development, and 197 countries have signed the Paris agreement.

The UN sustainable development goals consist of 17 global goals. These goals aim to act as a universal call for action in matters of ending poverty, protecting the planet and improving the lives and prospects of everyone, globally. All of the UN member states agreed to adopt the 17 goals in 2015 and the finish line to achieving the goals is set to 2030. The matter of reuse in the building sector is especially relevant for goal number 11-sustainable cities and communities and goal number 12-responsible consumption and production.[1]

The Paris Agreement is a global climate change agreement, adopted at the Paris climate conference (COP21) in December 2015. The Paris Agreement sets out a global framework to avoid dangerous consequences of climate change by limiting global warming to well below 2 °C and pursuing efforts to limit it to 1.5 °C. Norway is among the countries that have signed the Paris agreement and is therefore legally bound to follow it. Norway must reduce its total GHG emissions by 40% before 2030.[2]

One cannot discuss sustainability without mentioning circular economy. Today we live in the height of a consumer economy that consists of a ‘take-make-waste’ linear economic model. In a circular economy, however, natural resources and products are efficiently exploited and maintained for as long as possible in a product cycle, where a minimal amount of resources go to waste. Society’s transition into a more circular economy involves changes in design, production and consumer habits. A more efficient use of our resources reduces GHG emissions, slows down the loss of biodiversity, reduces pollution and contributes to new green workplaces and business models. The transition into a circular economy is a crucial part of the transition to becoming a low emission society and achieving the UN goals.[3]

Norway has one of the highest global rates of consumption per capita. In addition, over 97% of all material consumption in the country is not cycled back into the economy. Therefore, Norway does not only need to move towards a more circular economy, but it should also work on reducing its overall consumption, lowering its material footprint.

Norway's circularity metric is 2,4%. By implementing the scenarios explored in the report *The Circularity Gap Report Norway*, the circularity metric can be increased to 45,8% and consumption can be reduced by 64,8%. By achieving the scenarios described in the report, the carbon emissions from consumption are also reduced by 63%. The six scenarios in the report include circular construction, total transition to clean energy, circular food systems, green transport system, a strong repair, reuse & recycling economy and circular forestry and wood products.

Today, construction stands for 24,8% of Norway's total raw material consumption. This is the sector with the largest material consumption, and much of the country's resources are its capital formation, such as buildings. The GHG emissions from the building sector account for 6% of the total emissions. When including the emissions from the operational energy use in buildings, the emissions become 15% of the total national emissions. The report suggests interventions and strategies in order to make the construction sector more circular, shown in Table 1. The impact of implementing the interventions and strategies for circular construction is estimated to increase the circularity metric from 2,4% to 7% and reduce the material footprint by 37%.[4]

Table 1 Interventions, strategies and outcome for a circular construction scenario, as presented in The circularity gap report Norway.[4]

	Interventions	Strategies	Impact & Footprint
Circular construction	No extraction of virgin materials	Slow o Extend lifetime of buildings for longevity o Repurpose, renovate, refurbish, upgrade buildings	Circularity from 2,4% to 7,0%
	Cycle better and stop extracting new resources	Cycle o Reverse construction and sorting o Enable environment for smart material management	Reduction of material footprint by 37%, decrease to 144 million tonnes

The waste hierarchy pyramid, shown in Figure 1, is part of the EU Waste Framework Directive and illustrates the different measures for waste reduction. The goal is that waste will be handled as much as possible in the top layers of the pyramid, meaning that prevention of waste is the most favorable level. Disposal is situated at the bottom of the pyramid as the least favored outcome. Reuse is the second most favorable level on the waste hierarchy.[5, 6]

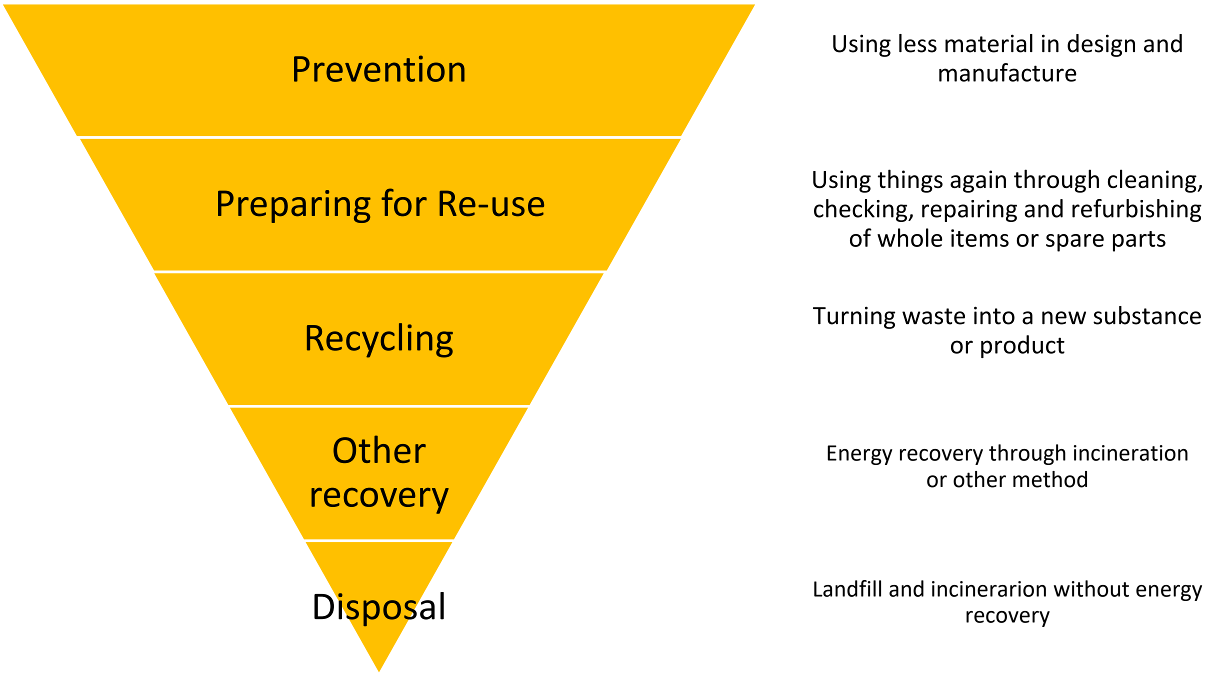
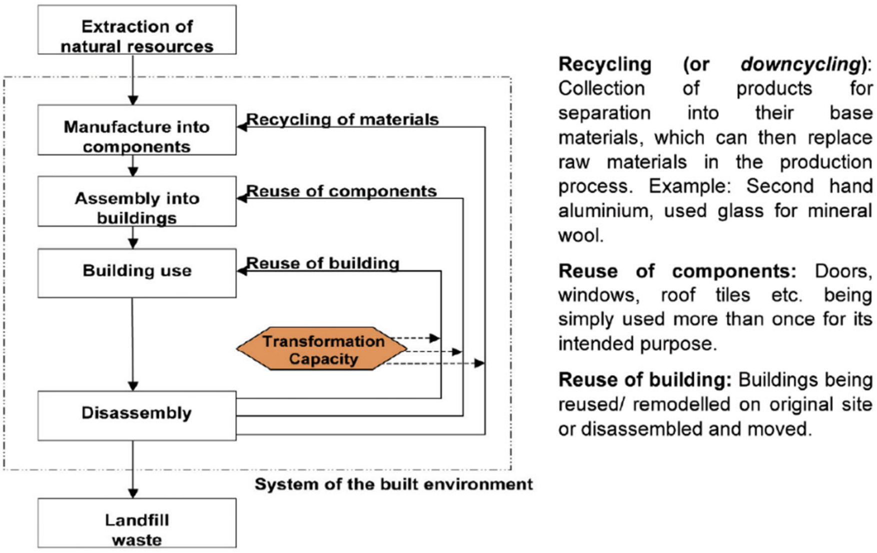


Figure 1 The waste hierarchy pyramid based on the EU Waste Framework Directive.[5]

1.2 Thesis description and objectives

The goal of this thesis is to give an in-depth understanding of reuse of building materials in Norway today and present qualitative descriptions and examples to inspire for more reuse in the future. The background study for this thesis shows that reuse is part of the solution to becoming a more circular economy and lowering material consumption, waste production as well as emissions.

Figure 2 below shows the recycling hierarchy in the context of the building sector. When we put the waste hierarchy pyramid in the context of the building sector, prevention entails the “reuse” of whole buildings. In other words, prevention is choosing not to demolish and to avoid building new constructions. Reuse, being the second most important measure for lowering waste production, can mean a number of things. Firstly, it can mean that we design new buildings with the idea that they will be easy to disassemble and therefore facilitate *future* reuse of the materials. This is often called Design for Disassembly, a design method that facilitates both the direct reuse of the materials and easier recycling at the end of the building's lifetime.[7] However, this thesis focuses on current reuse of materials and components from existing buildings.



Recycling (or *downcycling*): Collection of products for separation into their base materials, which can then replace raw materials in the production process. Example: Second hand aluminium, used glass for mineral wool.

Reuse of components: Doors, windows, roof tiles etc. being simply used more than once for its intended purpose.

Reuse of building: Buildings being reused/ remodelled on original site or disassembled and moved.

Figure 2 The recycling hierarchy in the context of the building sector.[8]

This thesis is about reuse of building materials and components in the Norwegian building sector. It is meant to look at the current situation but also the near-future development. The report is aimed at civil engineers, project managers, architects and other professionals that are interested in reuse of building materials.

The thesis aims at creating a holistic view of reuse in the building sector in Norway today, looking at many different aspects. Both information important from a "project management" point of view and "design" point of view have been included in the thesis. Here, project management entails matters of standards, laws and regulations, certifications and accounting for reduction of emissions from reuse. The part that might be more interesting from a design point of view is the solution examples presented in the result part of the thesis.

The aim of the results is to help projects realize targeted reuse in their projects. This is done by connecting GHG emissions and reuse of materials and components. The result part should give information on what building components and materials contribute to the highest embodied emissions and then give more targeted examples and inspiration for reuse solutions in these building components. The guide will then give qualitative examples and knowledge, not only on reuse but reuse that can contribute more to lowering the emissions of a project. The result part also aims at drawing knowledge from case studies as well as create new tools that can assist new projects with planning and documenting for reuse.

Reuse has in the past few years become an emerging and popular topic in the construction industry. Although there are limited examples of modern-day projects with large scale reuse, there is a rapid development in this field. Reuse is part of the solution both for lowering waste production and lowering a project's embodied emissions from materials. Regardless of the "hype" for reuse, the industry and product regulations are trying to catch up to the need for change. Hopefully, this thesis will be a useful contribution for the further development of reuse in the building sector.

Initially, the plan for this thesis was to focus on the ongoing project of Cissi Klein High School. Due to changes to their set targets for reuse in the project, it became difficult to make it a large part of the thesis. Instead of a full case study, Cissi Klein is now presented in subchapter 3.4.2 under project examples. Although not a lot of the thesis work focuses on this particular project, there are still interesting things to learn from looking at different projects.

1.2.1 List of research objectives

- A comprehensive literature review collecting information surrounding reuse in the Norwegian building sector.
- Connecting GHG-emissions and reuse by presenting LCA data by building part.
- Present examples with qualitative descriptions of reuse.
- Present project examples and experiences with reuse.
- Develop a flowchart to assist future projects with planning for reuse.
- Develop an excel sheet for documentation of reuse to assist future projects.
- Identify and discuss challenges with today's conditions in Norway for reuse of building materials.

1.2.2 List of research questions

- What is the current status on reuse in the Norwegian building sector?
- Which barriers do current projects face when they want to realize reuse of building materials?
- How can building projects achieve a more targeted reduction of ghg-emissions through reuse?

1.3 Report structure

The thesis follows a traditional research report structure with introduction, method, literature review, results, discussion and conclusion.

After the first chapter that includes the introduction, description and background for the thesis comes the second chapter which looks at theoretical background. This chapter focuses on introducing important theoretical principles used in the result part, such as life cycle assessment and explaining different types of emissions (2.1), presenting statistics of waste production in Norway (2.2) as well as NS 3451 Table of building elements (2.3) used to structure the result part (3.3) of the report. Subchapters 2.4, 2.5 and 2.6 look more specifically into reuse in Norway. Subchapter 2.4 describes the current national laws and regulations in place. Subchapter 2.5 looks at two different building certifications: FutureBuilt and BREEAM. Subchapter 2.6 describes two different methods used to account for reduction of emissions from reuse. Lastly, subchapter 2.7 presents tools to accommodate reuse. The tools consist mainly of literature sources on the topic, as well as research projects currently working on relevant objectives to this thesis report.

Chapter 3 presents the results of the thesis. The result chapter is divided into six parts: general recommendations, embodied emissions per building element, solution examples, project examples (case studies) as well as two tools developed regarding planning for reuse. The project examples present two different projects that each have goals regarding reuse.

Chapter 4 discusses the findings of the thesis and its research questions as well as discussing faults in the method of this report. Chapter 5 presents the conclusion, while chapter 6 gives examples of further work that can be done on the matter of reuse.

1.4 Method

The method of this report is mainly literature review. The largest part of the thesis collects various written sources in order to create a holistic overview of the subject. The report work is based on qualitative research. The qualitative research types used are case studies and record keeping. The record keeping method means the collection of reference material and relevant data. The data sources are existing research, reliable documents and other sources of existing information.

It was decided that a good way to structure the solution example findings of the result part was by using the structure of NS 3451 – Table of building elements. The data on material emissions (3.2) was chosen from the ZEN Report No.24, which presents the largest data collection of embodied emissions of various building types in Norway, and the data is presented with the structure of NS 3451. Thereafter, the data presented in subchapter 3.2 is used in order to give practical solution examples in subchapter 3.3 that focus on building parts that are connected to the largest total embodied emissions.

The result solution examples (3.3) are a qualitative analysis of which building materials and components will contribute most to the reduction of the embodied GHG emissions of a project. There were not enough existing sources to make a full quantitative analysis of the result part of the thesis. However, wherever relevant numerical data was available, this has been presented in the overall analysis.

There are also two case studies that are part of the overall qualitative research. By looking at multiple case studies, different experiences and settings have been explored and compared. The case studies differ in location, function, project type and goals for reuse giving a broader understanding as well as providing additional knowledge on what works and what obstacles exist.

By using all the information collected throughout the report, two tools are developed aiming at helping future building projects with planning and realizing reuse of materials and components. The first tool is a flowchart created to visually present the findings of the report as a collective result. The second tool is a table made by using Microsoft Excel.

2. Theory

2.1 Life Cycle Assessment

In the standard NS-EN 15643:2021, it is stated that the European (and Norwegian) Standards aim to use a life cycle approach to provide a system for the sustainability assessment of buildings and civil engineering works. Although the sustainability assessment works with quantifiable indicators, the European Standards developed do not set actual benchmarks.

The standard NS-EN 15643:2021 defines sustainability in the building sector and splits it into three aspects: an environmental aspect, an economic aspect and a social aspect.[9]

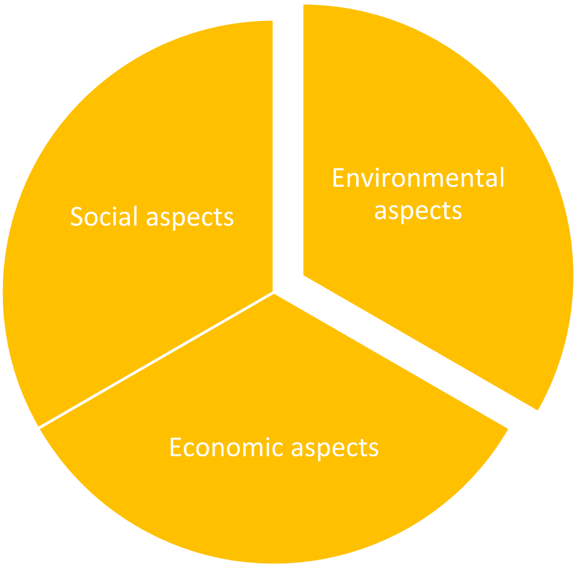


Figure 3 The three aspects of sustainability in construction works as described in NS-EN 15643:2021.[9]

This thesis focuses on the environmental aspect of sustainability in the building sector. The standard NS-EN 15804 provides more specific environmental indicators for Life Cycle Impact Assessment.[10]

Life cycle assessment (LCA) is defined in the standards as a "compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle".[11]

By using the LCA methodology, one can quantify the global warming potential of a whole building or a single component by measuring it in gCO_2eq. The measurement of carbon dioxide equivalents is defined as "*a metric measure used to compare the emissions from various greenhouse gases on the basis of their global-warming potential (GWP), by* *converting amounts of other gases to the equivalent amount of carbon dioxide with the same global warming potential*".[12] This can be used to assess the environmental sustainability of a material or a project and compare different solutions to each other. Another use of the method is to identify which building parts or stages contribute with the largest impacts. In this way, more targeted and impactful strategies can be implemented in order to decrease the emissions during the building's life cycle.

LCA is organized into different life cycle stages, as shown in Figure 4 bellow. Every life cycle assessment needs to specify the system boundary of the calculations, specifying which life cycle stages have been taken into account in the assessment.

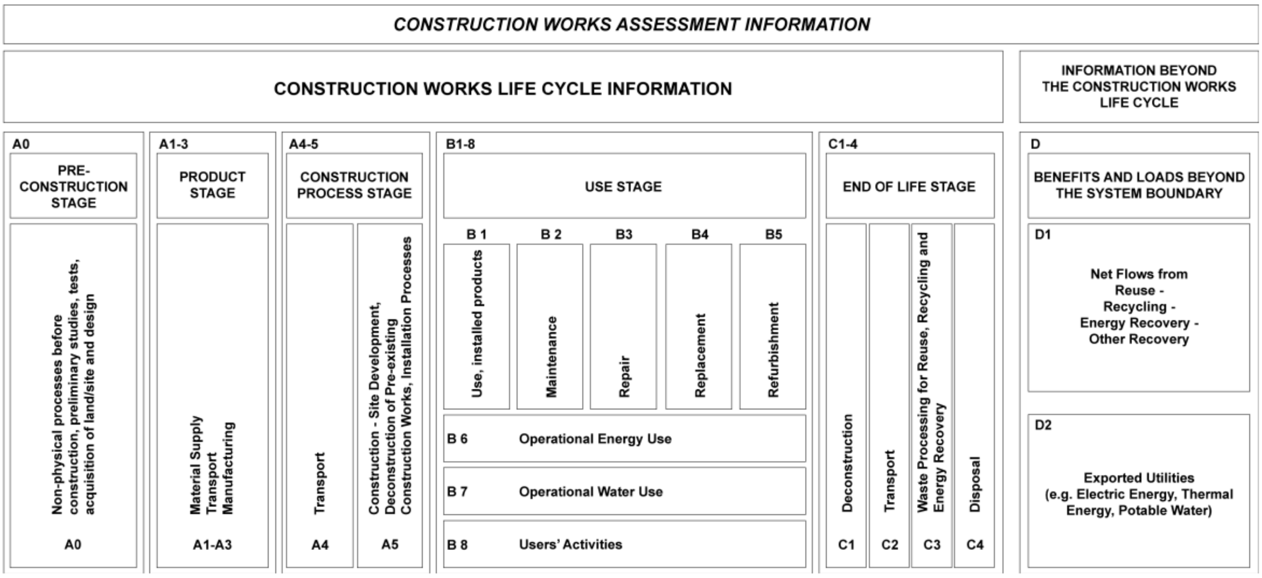


Figure 4 Life cycle stages used for LCA in buildings. Source: NS-EN 15643:2021

With increasing energy efficiency of buildings, the relevance of the embodied GHG emissions is increasing in both relative and absolute terms. This is shown in Figure 5, which gives an example of distribution of GHG emissions throughout a building's lifetime, divided per year and according to the previous TEK10 standard and the passive house standard.[13] In the diagram, we see that the emissions due to energy consumption in the use stage of the building are somewhat higher than the material emissions. However, the gap between operational emissions from energy use vs embodied emissions from materials is very small when a building meets the passive house standard.

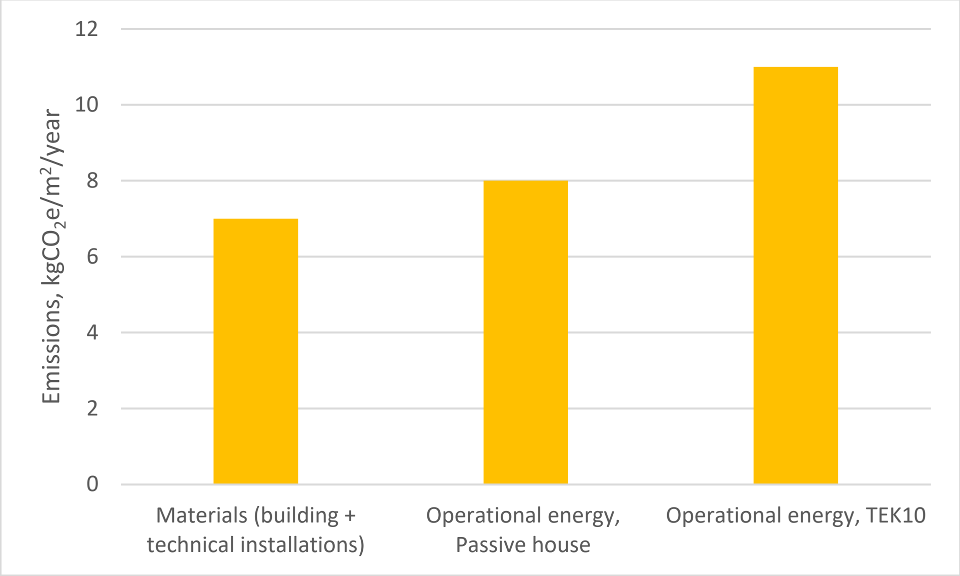


Figure 5 Example of distribution of GHG emissions throughout a building's lifetime, divided per year and according to the previous TEK10 standard and the passive house standard.[13]

In the near future, the electricity grid will become greener and therefore the embodied material emissions will become an even larger part of the total building emissions.[14]

The projected change (shown in Figure 6) in the emissions of the grid power is taken into account by the ZEB Research Centre in Norway. In the ZEB definition guideline[15], Norway is considered to become increasingly integrated in the European power grid. The EU has set policy targets towards mitigating climate change by drastically reducing the carbon intensity of the electricity grid towards 2050 and after. Considering that LCA calculations look at the whole lifetime of a building, often set to 60 years, such future changes in the power sector should be considered.[15]

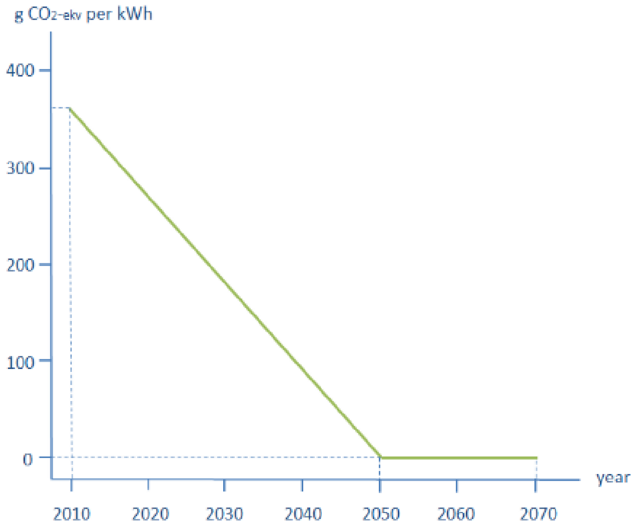


Figure 6 Average (2010-2070): 132 gCO_2eq/kWh. The CO_2 factor scenario for grid electricity employed by the ZEB Research Centre.[15]

2.2 Waste material from the building sector in Norway

Waste from the building sector stands for 25% of all waste produced in Norway. 46% of the waste comes from demolition of buildings, 30% from new construction and 24% from renovation/maintenance work.[16] Table 2 below presents the waste quantities from building activities in 2020 in both tons and percentages. The table also includes the difference in percentages between the 2019 and 2020 waste generation. The numbers show a total increase of waste production of almost 10%, where most of this is due to an increase of waste from demolition of buildings.[17]

Table 2 Generated quantities of waste from new construction, rehabilitation and demolition measured in tons.[17]

			Difference in percentages
	Tons	Percentage	2019 - 2020
2020			
Building activity in total	**2135747**	**100**	**9.6**
New construction	646742	30.3	-1.7
Rehabilitation	510806	23.9	3.3
Demolition	978200	45.8	22.9

Large quantities of waste represent valuable material resources. The building sector is the largest material consumer in Norway. This sector also generates large amounts of waste where a lot can be relatively clean and fit for reuse. 40% consists of brick and concrete, 14% wood and 13% asphalt.[18] An overview of the statistical data on waste production per material category presented in both tons of waste and percentages is presented in appendix A. Figure 7 shows the distribution between different end-of-life treatments of construction waste. After disposal, 54% of the waste from the building industry is taken to material recycling, 31% to energy plants and 11% to landfill. There is a large potential for increased reuse and recycling.[13]

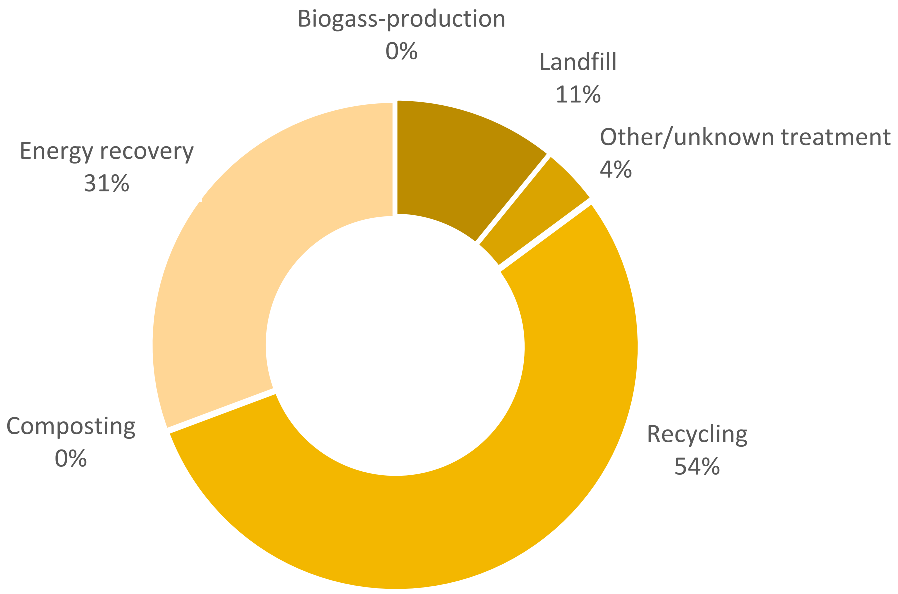


Figure 7 Waste treatment for waste from the construction industry in Norway.[13]

2.3 NS 3451 – Table of building elements

The Norwegian standard NS 3451 provides a table of building elements.[19] The standard is organized in three levels with an increasing level of detail from one-digit to three-digit levels. Below, the table of building elements for 1- and 2- digit building element numbers is presented.

Table 3 Table of building elements according to NS 3451.[19]

1-digit building element number	2-digit building element number
2 Building	20 Building, general 21 Ground and foundations 22 Load-bearing systems 23 External walls 24 Internal walls 25 Slabs 26 Roof 27 Fixed inventory 28 Stairs, balconies, etc. 29 Other building parts
3 HVAC installations	30 HVAC installations, general 31 Sanitary 32 Heating 33 Fire extinguishing 34 Gas and compressed air 35 Process cooling

	36 Air treatment
	37 Comfort cooling
	38 Water treatment
	39 Other HVAC installations
4 Electrical power	40 Electrical power, general
	41 Basic installations for electric power
	42 High voltage power supply
	43 Low voltage power supply
	44 Light
	45 Electrical heating
	46 Backup electrical power
	47 Not to be used
	48 Not to be used
	49 Other electrical power installations
5 Telecommunication and automation	50 Telecommunication and automation, general
6 Other installations	60 Other installations, general
7 Outdoors	70 Outdoors, general
	71 Cultivated terrain
	72 Outdoor constructions
	73 Outdoor piping systems
	74 Outdoor electrical power
	75 Outdoor telecommunication and automation
	76 Roads and sites
	77 Parks and gardens
	78 Outdoor infrastructure
	79 Other outdoor installations

2.4 Laws and regulations regarding reuse of building materials

This chapter looks at the laws and requirements from the Norwegian Building Authority (DiBK) when using or selling reused building materials. The Norwegian Building Authority has created an online guide for selling reused building materials.[20] The guide provides information regarding the requirements and documentation needed prior to selling used goods.

The main goal of the Norwegian Building Authority is that the regulations ensure good, resilient and safe buildings. The framework of the Norwegian Building Authority constitutes two sets of regulations that must be met.

The first set of regulations regard selling or giving away a building material or component. The Construction Products Regulation is an EU regulation. The Regulations on documentation of construction products (DOK) include the demands from the European Construction Products Regulation (EU nr. 305/2011) as well as Norwegian regulations.[21] The second set of regulations set demands for the building and is the Norwegian technical regulation (TEK17).[22] As mentioned, both these sets of regulations have been created primarily with construction from new materials in mind and not reused materials or components. Before July 2022 the laws and regulations framework for new and reused building materials were identical. The regulations were less well adapted for reuse of materials.

The Norwegian Building Authority cannot change or add requirements to DOK that go against the EU requirements. The most important requirements that cannot be deviated from are fire and safety. The EU is expected to revise the documentation of construction materials requirements in order to better adhere to reused materials.

DOK currently demands that all building products that are sold or given away must have valid documentation of the characteristics of the product. The regulation does not set demands for the quality of the products, and it is sufficient to just document one characteristic. There is a standard in place that describes which characteristics are relevant for the various building materials/products and how these should be documented. These standards are typically not adapted with reused materials in mind. Documentation makes it easier for the contractor to choose materials with the right qualities before they are used in the building.

In cases where the original product documentation is available when reuse is planned, there must be a certainty that the product has retained the same characteristics as when it was produced. If this is not feasible, the other solution is to create new documentation of the material/product characteristics for the building product that one wants to reuse. This must be done according to an existing standard or according to ETA (European Technical Assessment).

In the technical regulation (TEK17), it is stated that you should know the characteristics of what you build into your building and this should be documented. This is the case regardless of whether the measure is subject to application or not as long as it is within §20-1 of the Norwegian Planning and Building Act (PBL).[23] §3-1 (2) of TEK17 states "*Verification shall be provided, before products are incorporated into a construction work, showing that the products have the properties necessary to ensure the completed construction work will comply with the requirements in the Regulation.*". In §9-5 regarding construction waste, TEK17 states ''*Products suitable for reuse and material recovery shall be chosen.*''.[24]

Building products need to have documentation showing their quality, regardless of whether they are new, used or they haven’t been sold outside the site. Today, this documentation is required in order to ensure quality and safety in buildings.[25]

Before 1st of July 2022 there was a difference between reusing materials already available on site from a demolition or renovation and using a reused material or component from another building project. If the reused material was sourced from outside the building site where the material was going to be installed, the material had to be re-certified according to DOK in addition to meet the TEK17 regulations in general. However, for reuse on the same site, meaning the material was reused on the site it was sourced from, only the TEK17 regulations had to be met.

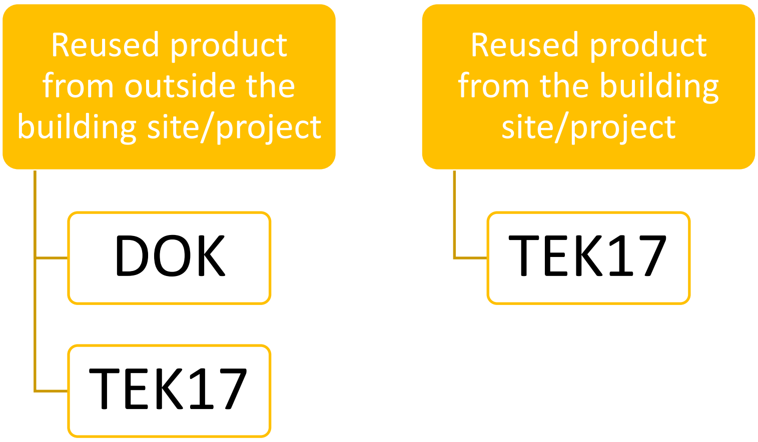


Figure 8 Regulations that had to be met before July 2022.

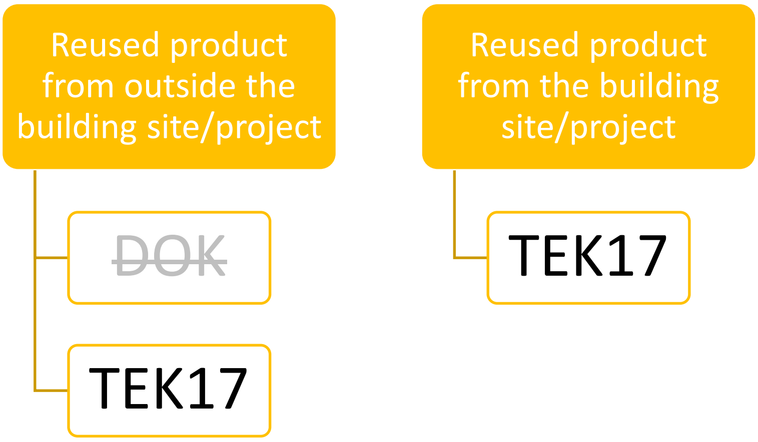


Figure 9 Regulations that have to be met from July 2022.

The Norwegian Building Authority has gotten approval to make changes according to the suggestion that they sent in for hearing to the Norwegian Ministry of Local Government and Regional Development. #

The government issued a change in the requirements that came into effect starting on the 1st of July 2022. These changes were made specifically to make reuse easier for building projects and to stimulate growth in Norway's circular economy. The first change that has come into effect is the removal of the DOK requirement for reused materials. It is still however required to meet the TEK17 requirements that are focused on health and safety. In practical terms the removal of the DOK documentation requirements removes the added workload of redocumenting the product prior of selling them from the demolition or rehabilitation site. The responsibility is then only in the reuse retailer or new project group, in other words the second value chain, to ensure that the reused product meets the TEK17 requirements for the new function that the material will have.[26]

The second change in the requirements that came into effect starting on the 1st of July 2022 is an added paragraph in the TEK17 requirements. It is stated in §9-7 of TEK17 that residential blocks and office buildings that undergo big renovations or demolition are required to do a reuse-mapping. The reuse-mapping should result in a report that describes all building elements that are suited for reuse. Paragraph 9-7 also states a few guidelines on what should be included in the reuse-mapping report and that all the identified building elements and materials fit for reuse should be presented in a table according to NS 3451.[27]

2.5 Criteria for circular buildings

Currently, the Norwegian building regulations do not specifically set a limit for GHG emissions from materials for building projects. In addition, no regulations are in place with criteria for reuse other than encouraging waste reduction. New measures to reduce material emissions in the building sector will most likely be implemented in the regulations in the near future. The interest in the market for sustainable buildings is increasing and many projects set higher environmental aims than the regulations call for. Two certification platforms commonly used in Norway are presented in the following subchapters.

2.5.1 Criteria for circular buildings from FutureBuilt

FutureBuilt Zero has created a set of criteria for net GHG emissions throughout the building lifetime. They have also published a description of the methodology for the calculations. The criteria get stricter with time, in order to hit the national climate goals for reduction of emissions. The calculation methodology therefore also considers the time at which the emissions connected to the building occur and how this affects global warming.

FutureBuilt Zero sets criteria for maximum emissions for a building's contribution to global warming throughout its lifetime, and includes potential emission gains from carbon storage, reuse of materials, material recycling and energy recovery and energy export. The criteria focus on emission reductions early in the building's lifetime, but they also give incentives to prevent future emissions by including potential gains after the building's end of life.

Today's GHG emissions have to be reduced rapidly in order to meet the national climate goals. Figure 10 shows GHG emissions for buildings today. The blue dashed line shows how the emissions with "today's practice" have to be reduced in the future. The orange line in the graph indicates "today's best practice" which also sets the criteria for FutureBuilt Zero. The criteria tighten up every year in order to achieve a 50-55% reduction in 2030 and a 90-95% reduction in 2050 compared to the 2020 numbers. The criteria set apply per used indoor floor area (m^2) over a 60-year lifetime.[31]

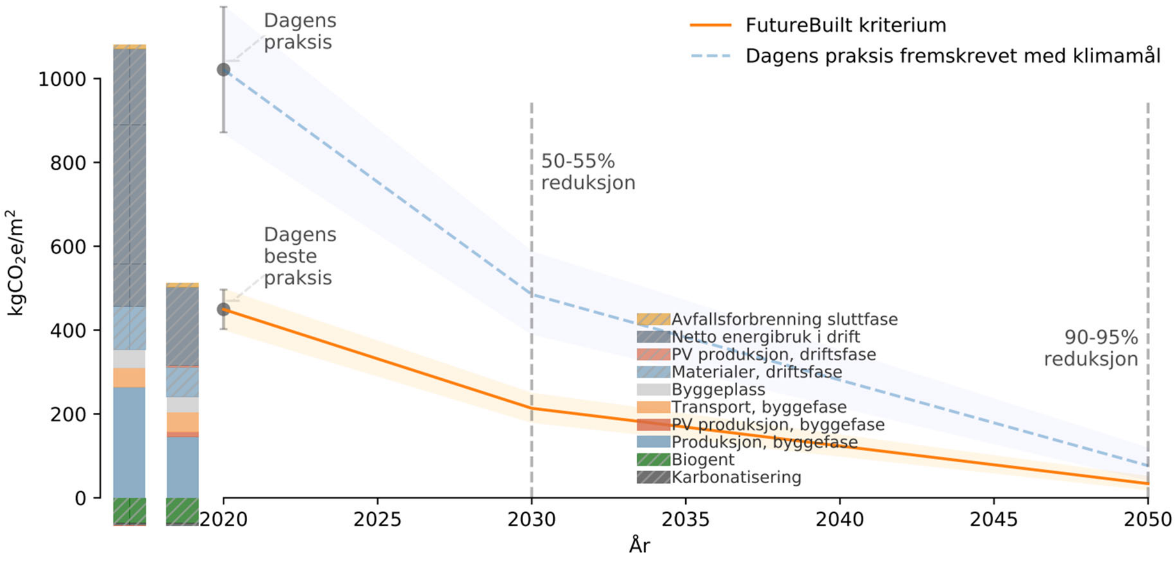


Figure 10 FutureBuilt's main criteria towards 2050. GHG emissions based on "today's practice" and "today's best practice" are presented and they decline in order to meet the national goals regarding future reduction of emissions.[31]

2.5.2 Criteria for reuse in buildings from BREEAM

BREEAM is one of the most commonly used built environment sustainability assessments. BREEAM is a certification scheme managed by the Building Research Establishment (BRE) in the United Kingdom. BREEAM has an adapted version to fit the Norwegian setting better, called BREEAM-NOR.

A building can get BREEAM-NOR certified on five different levels: Pass, Good, Very Good, Excellent and Outstanding. For each level, the sustainability of the building increases. There are nine categories in BREEAM-NOR:

- Leadership
- Health and indoor environment
- Energy
- Transport
- Water
- Materials
- Waste
- Area-use and ecology
- Pollution

Each category has a set of criteria or measures that lead to a reduction of the building's environmental impact. The more measures the project implements and can document, the more points the project gets. The total number of points earned then decides which certification level the project gets.[28]

BREEAM-NOR has released an updated version "BREEAM-NOR v6.0" in 2022. There, reuse has become a part of the criteria. The previous version of BREEAM-NOR was released in 2016. The main difference in the point weighting between the previous and the current BREEAM-NOR is that the energy category has reduced weighted importance while materials, health and indoor environment, as well as area-use and ecology have increased weighted importance. Some of the new minimum criteria implemented in BREEAM-NOR v6.0:

- Emission calculations are now a minimum requirement for Pass
- Reuse-mapping is now a minimum requirement for achieving Excellent, if there is an existing structure on the building site
- 75% of waste to be sorted is now a minimum requirement for achieving Pass
- 70% of waste to be prepared for reuse, recycling or energy recovery is now a minimum requirement for achieving Excellent

Table 4 shows the waste and material handling needed to avoid that materials that can be used for reuse, recycling or energy recovery end up in landfill, including minimum requirements and points given.

Table 4 Minimum requirements and points given for waste sorting and avoiding landfill in BREEAM-NOR v.6 [29]

Points	Percentage sorted waste	Percentage prepared for reuse, recycling or energy recovery	Minimum requirement

Minimum requirement, No points	75%	-	Pass
1	85%	50%	
2	90%	70%	Excellent

Within the materials category of BREEAM-NOR, there are multiple new topics regarding reuse. There is a new subcategory called Mat 06 – material efficiency and reuse, where reuse-mapping is set as a minimum requirement if there is an existing building on site.

There are different reuse requirements set for demolition projects, new constructions and for future reuse.

Demolition

- There should be a reuse-mapping of the project that gives a set of recommended measures
- A minimum of 10 measures have to be carried out
- A minimum of 5 reuse components should be reused

New construction

- A minimum of 2 reuse components should be brought in from outside the project site

Future reuse

- Create a resource overview (list of materials) and look at the building as a material bank
- Design for future reuse

Another new subcategory in BREEAM-NOR v6.0 is Mat 07 – Readiness for change and reusability, which gives up to 3 points.[29]

2.6 Calculation methods for reuse

2.6.1 Calculation methods in standards

The Norwegian standard 3720[30] describes a method for greenhouse gas calculations for buildings. The standard gives to a lower extent a set (a loose) system boundary and procedures, contrary to the more set systems and procedures presented from FutureBuilt Zero, which is further described in the next subchapter. NS 3720 has aimed to include a broad scope but at the same time give flexibility to adjust the system boundaries in order to fit the aims of the calculations. For instance, the standard provides possible scopes for the calculations but does not definitively state what is to be included in an LCA.

In NS 3720, chapter 7.7 regarding holistic emissions calculations, the standard presents four different predefined scope boundaries. The various scopes are shown in Table 5 where they are divided between basic calculations with or without location and advanced calculations with or without location.

Table 5 Various predefined scopes for overall greenhouse gas calculations, basic calculation without and with location, and advanced calculation without and with location as presented in NS 3720:2018.

	Without location	With location
Basic	The greenhouse gas calculation must include greenhouse gas emissions from the building site, materials, energy in operation. Materials must include the content of building element number 2 Building in accordance with NS 3451 as well as materials that are included in local energy production equipment that is not covered by NS 3451.	The greenhouse gas calculation must include greenhouse gas emissions from site development, building site, materials, energy in operation, transport in operation. Materials must include the content of building element number 2 Building in accordance with NS 3451 as well as materials that are included in local energy production equipment that is not covered by NS 3451.
Advanced	The greenhouse gas calculation must include greenhouse gas emissions from the building site, materials, energy in operation and include materials that are included in building element numbers 2 Building, 3 HVAC installation, 4 Electrical power, 6 Other installations, 7 Outdoors in accordance with NS 3451 as well as materials that are included in local energy production equipment that is not covered by NS 3451.	The greenhouse gas calculation must include greenhouse gas emissions from site development, the building site, materials, energy in operation, transport in operation and include materials that are included in building element numbers 2 Building, 3 HVAC installation, 4 Electrical power, 6 Other installations, 7 Outdoors in accordance with NS 3451 as well as materials that are included in local energy production equipment that is not covered by NS 3451.

Following the standard will lead to different boundary scopes and methods between projects. This flexibility in the LCA calculations makes it difficult to directly compare different projects.

Reuse of building materials and components is not greatly discussed in NS 3720. Regarding where to account for reused materials, some information is given in chapter 6.3 of the standard:

"*Consequences linked to reuse, recycling and energy recovery outside of the system boundary for the analysis can be calculated in module D, and the results in module D must be reported separately. Where a material flow crosses the system boundary and has a financial value or has reached the stage where the material ceases to be waste, and consequently replaces another product, the greenhouse gas emissions can be calculated.*" [30]

2.6.2 Calculation method from FutureBuilt

FutureBuilt Zero provides a set method of LCA calculations with set system boundaries.[31] The method developed by FutureBuilt Zero is based on the standard NS 3720. Due to the set system boundaries, a larger scope will often be included compared to calculations done only using NS 3720. The calculation method is identical to the one described in the standard with a few exceptions. The most relevant differences are that FutureBuilt Zero includes the positive effects of reuse in the main results, instead of showing these in module D.

Products that in the building phase are reused from previous buildings will lead to avoided emissions from waste management and from the production stage. When reusing a material in a new construction, FutureBuilt Zero gives a simple calculation method to incorporate the benefits. The method estimates that the reused material reduces the emissions from the production stage (stages A1-A3) by 80% of an equivalent new material that would have been used otherwise. FutureBuilt Zero also opens up for more specific emissions reduction calculations from reuse instead of the simplified general method described above. The gains from reuse can only be included for original material use, not material replacement in a building.

Equation for a simplified method of calculating emissions of a reused material, developed by FutureBuilt Zero:

$$E_{\mathrm{A1-3,documented\ reuse}} = 0{,}2 \cdot E_{\mathrm{A1-3,equivalent\ new\ product}} \quad [\mathrm{kgCO_2e}]$$

Building products that are partly or completely fit for future reuse will be able to substitute production of equivalent new products in the future and therefore reduce emissions and material use. It is, however, difficult to foresee how materials in existing buildings will be handled in 50-100 years or more. It is still a good idea to design for disassembly and reuse in new buildings today since this will increase the chances for reuse in the future. FutureBuilt Zero's calculation method gives a future negative climate effect of 10% of today's production emissions for these materials. This value considers technological advancements and time. The reusability of the product has to be documented and meet FutureBuilt's criteria for circular buildings. The calculations should not include the emissions from incineration of materials with documented reuse potential. The gain from future reuse is only applicable to original material use and not material replacement in a building.

Equation for a simplified method of calculating emission reduction from future reuse, developed by FutureBuilt Zero:

$$E_{\mathrm{D,reusability}} = -0{,}1 \cdot E_{\mathrm{A1-3,documented\ reusability}} \quad [\mathrm{kgCO_2e}]$$

2.7 Tools

Grønn Byggallianse, BREEAM-NOR and Future Built are three resources for building more circular buildings in Norway. Other companies also provide services to accommodate reuse or upcycling of building materials. Since reuse is a relatively new focus in the building sector there is currently a lack of experts and detailed tools on the subject. Therefore, ongoing research is also mentioned in this part, both from within Norway and outside.

Grønn Byggallianse and Statsbygg have created a guide on how to do and order a reuse-mapping (original title in Norwegian: Ombrukskartlegging og bestilling – slik gjør du det!). It is a practical tool with document template suggestions for when a commission for reuse-mapping is ordered prior to a demolition or rehabilitation project.[32]

The Norwegian standard *NS 3682:2022 Hollow core slabs for reuse* is a valuable tool for reusing concrete slabs of this type.[33]

Tools to account for reuse in your embodied emission assessment in a project are presented in chapter 2.6 of this thesis report. In the chapter, two methods for LCA accounting of reused materials are presented: according to the standards and a method developed by FutureBuilt.

Loopfront is a Norwegian based company that has developed a subscription-based platform that aims at making reuse easier. The platform covers the entire process from reuse survey and documentation to collaboration, logistics and reporting. The company focuses on making reuse easy and profitable.[34]

Resirqel is a Norwegian company that helps its clients achieve reuse in their building projects. Their services include reuse consultations, recertification of materials, logistics and sales of reused materials from the company's storage.[35]

2.7.1 Ongoing research

The following research projects are all looking at reuse in the building sector. Although these projects are not yet completed, some of them already have result reports and tools already published. The two latter research projects are based in Norway and it showcases how the industry and research institutions as well as the government are interested in reuse.

Interreg FCRBE – Facilitating the circulation of reclaimed building elements in Northwestern Europe

The FCRBE project is a collaboration between Belgium, the UK, the Netherlands and France and is funded by the European Union. The project has created a series of tools and methods to help different parties in the building sector to implement reuse.

There are also 37 case studies on reclaiming and reusing building elements, divided between the collaborating countries. The timeline of the project is 2018-2023. The research project has already published a number of reports and guides to their reuse toolkit website.[36]

SirkBygg: Circular new construction – Design for Disassembly

Original project name: SirkBygg: Sirkulære nybygg – Design for bygging for demontering og ombruk

This research project is led by Sintef. The project started in November 2021 and will go on for 4 years. The project's aim is to develop solutions that make new constructions become good material banks. Design for Disassembly with a focus on large structures made of steel, wood and concrete will be researched and carried out in project pilot buildings.[37]

REBUS – Reuse of building materials; a USer perspective

REBUS is a research project focused on reuse of building materials. The project started in January 2020 and will continue until 2023. 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. The project is divided into five work packages, which are presented in Figure 11 below. This is one of the most relevant research projects in regard to this thesis since it connects reuse with LCA. Another interesting work package of the project is the plan of creating a toolbox for reuse based on pilot testing.[38]

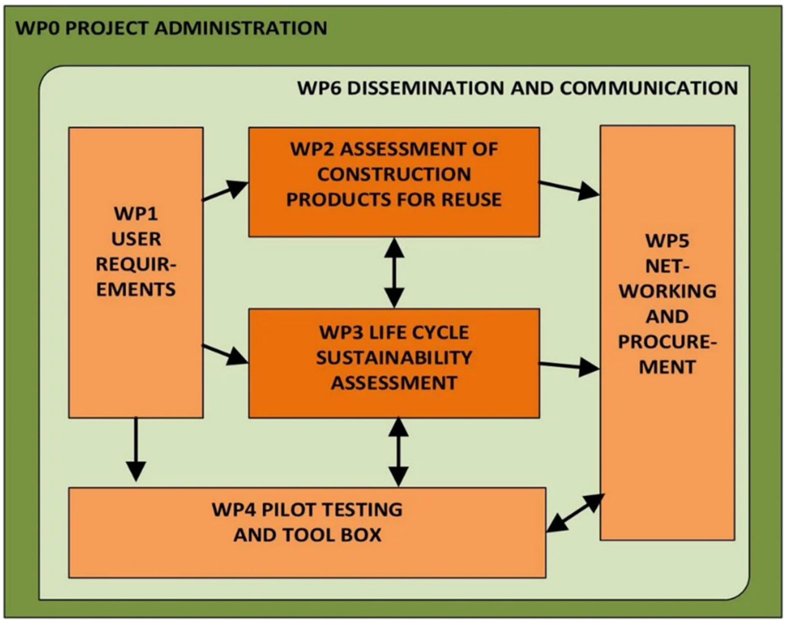


Figure 11 REBUS work package structure and how they relate and interact to each other.[38]

Although REBUS is still in the time of writing an ongoing research project, some papers have already been published. One of these is a guideline on documentation of performance for reuse materials (original title*: Ombruk av byggematerialer. Veileder for dokumentasjon av ytelser.*).[49] It focuses on visual assessment of reuse on four different categories of products: interior glass walls, windows and doors, ventilation parts and sanitary equipment. Another published report focuses on the reuse of paving stone.[58]

3. Results

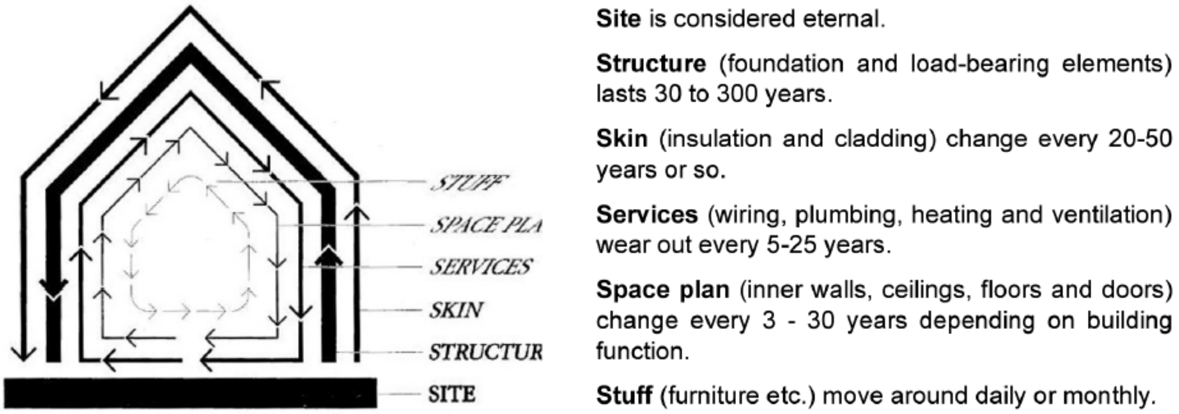
3.1 General recommendation

Rich countries like Norway have a large material consumption that must change quickly. We need to move away from today's linear economy and towards a more circular economy both to mitigate greenhouse gas (GHG) emissions and to reduce the extraction of natural resources.

Reuse is one of the solutions towards a more circular building sector. Ideally, many different measures must be used in new build and renovation projects in order to meet the EU's and Norway's climate targets towards 2030 and 2050. Other sustainability measures are lowering operational emissions, waste reduction, area efficiency, choosing renovation instead of demolition and building new, designing with flexibility, generality and elasticity, to name a few.[13]

Based on the doctoral dissertation of Anne Sigrid Nordby, *Salvageability of building materials*, a list of six general recommendations that help with reuse are presented below. These can both be implemented when designing for reusing materials in a project now or for designing a building with future reuse in mind.[39, 40]

I. Sensible layering
Think about the relation between the technical lifetime of components and the service life of the building the components are part of. Sensible layering of materials and functions means considering the pace of maintenance and exchange of the material in a building part. This is well illustrated in Figure 12 showcasing how different parts of a building, like the structure, technical services and furniture, each get upgraded or changed at a different pace.



Site is considered eternal.

Structure (foundation and load-bearing elements) lasts 30 to 300 years.

Skin (insulation and cladding) change every 20-50 years or so.

Services (wiring, plumbing, heating and ventilation) wear out every 5-25 years.

Space plan (inner walls, ceilings, floors and doors) change every 3 - 30 years depending on building function.

Stuff (furniture etc.) move around daily or monthly.

Figure 12 Building layers and their relation to time.[41]

II. Limit the number of different materials.

Minimize the number of materials, components and connection points.
Choose mono-material components. This makes both reuse and recycling more likely.
Avoid treated surfaces and harmful substances.

III. Long lifetime
Create durable components that can be used in more than one building lifetime.
Think about how the material/component can handle multiple disassemblies and reassemblies.
Choose components that have esthetic qualities. We keep longer something we like and think is nice.

IV. High generality
Whenever possible, choose standard dimensions and modular design.
Create components with moderate size and low mass.
Create components with low complexity and plan for the use of common tools.

V. Flexible connections
Use reversible connections between component parts and between building parts. This often means opting for mechanical connection methods such as bolts and screws, rather than chemical connections like for example glue.
Facilitate for disassembly.

VI. Accessible information
Mark materials and component types and coordinate this with information about the building’s system.
Mark connection points and make sure they are visible and accessible.

The recommendations listed above are focused on the design part of a project. From a project management side, there are a few useful recommendations from Grønn Byggallianse’s guide on reuse.[32] The general recommendations are:

- Use a reuse-mapper
- Introduce the process of reuse early on in the project
- Involve different professionals in the reuse matter, such as carpenters, architects etc.

Legal recommendations

The materials and components have to meet the legal requirements set by TEK17 and DOK (for Norway). A detailed description of the Norwegian laws and regulations regarding reuse is found in chapter 2.4 of this thesis. It is important to note that the materials and components have to meet the criteria set for their new function. For example, if clay bricks sourced from a load-bearing wall are to be reused as floor tiles, the bricks must be tested and recertified for their new function, as floor tiles.

3.2 LCA – Embodied emissions per building element

At the time of its publication in 2020, the ZEN Report No.24 was the largest data collection of GHG emissions in Norwegian buildings. Results from the report are presented in Figure 13 and Figure 14 below. Relevant data and graphs from the report are added in appendix B of the thesis.

The data in the ZEN Report is collected from LCA studies for Norwegian buildings. Figure 13 presents the average GHG emissions from all the collected studied data in kgCO$_2$e/m^2/year per building element. The building elements not presented in Figure 13 have not been included as they were not included in the original LCA calculations. The majority of the LCA studies have calculated the emissions from element *2 Building* (approx. 100 studies), whereas few studies have looked at the emissions of other building elements (varying from 1 to 26 studies). Building element *49 – Other electrical power installations* is typically solar cell installations.

Figure 14 presents the percentage relation between the different building element categories. The largest sum of emissions is connected to *2 Buildings* followed by element category *7 Outdoors* and *4 Electrical power*. It is important to acknowledge the uncertainty connected to the results presented for elements 31-79 due to the limited source data. The LCA calculations for the material emissions have included life cycle stages A1-A3 and B4, meaning the emissions connected to the production phase of a product and their replacement. The studies used for the ZEN report have included residential houses, office buildings, kindergartens, schools, and other building types.[42]

The next chapter, Solution examples, focuses on the building elements with the highest material emissions.

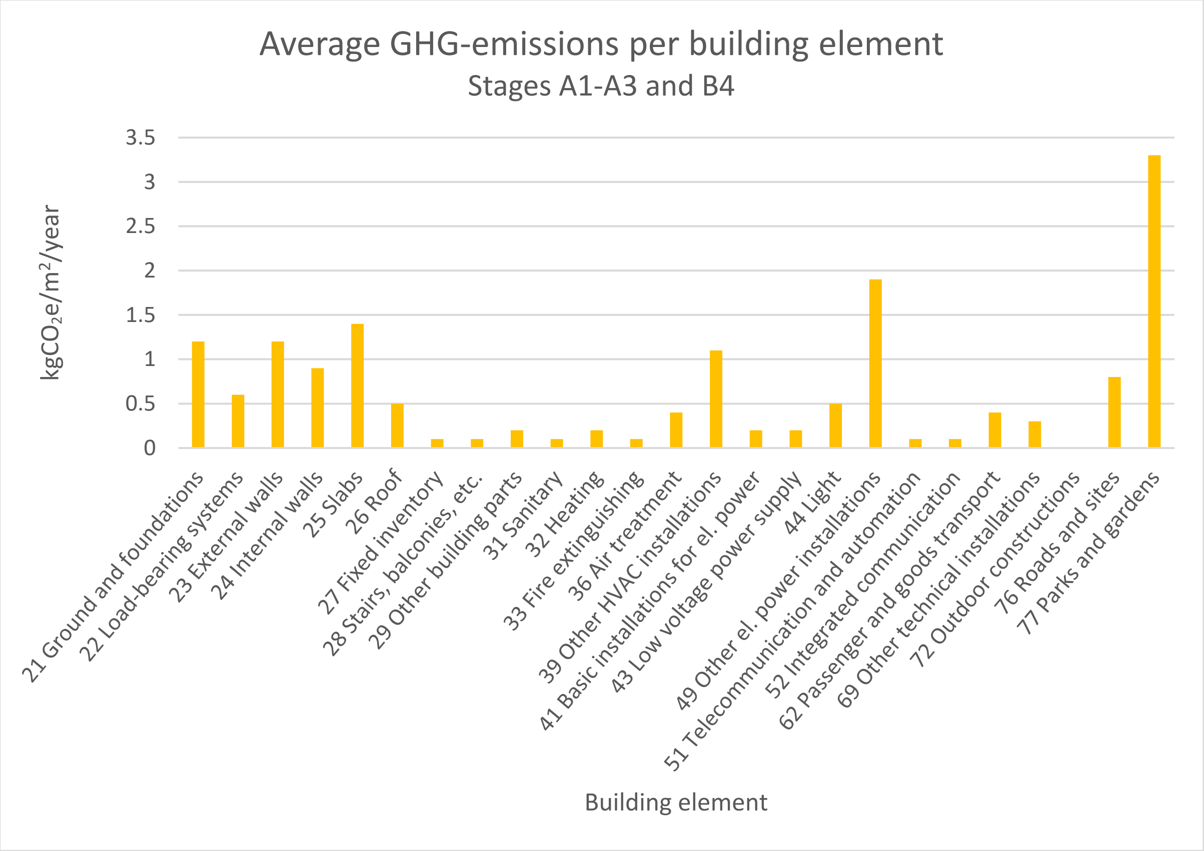


Figure 13 Average GHG emissions per building element, based on data from the ZEN Report No.24.[42]

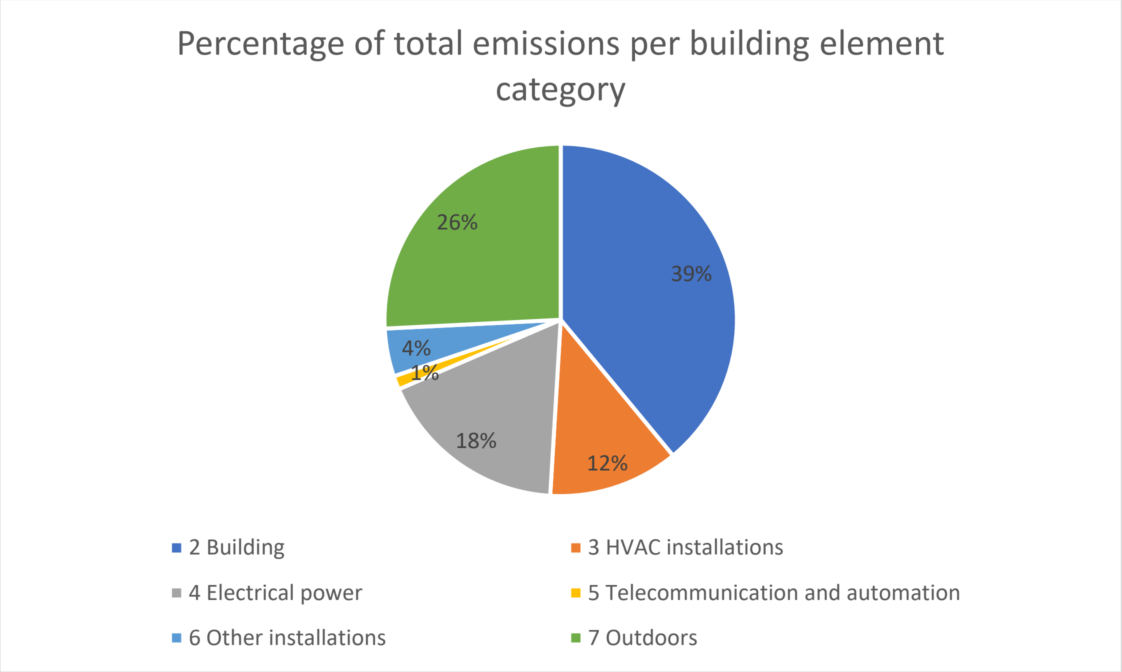


Figure 14 Percentage of total emissions per building element category, based on data from the ZEN Report No.24.[42]

3.3 Solution examples

The aim of the example solutions presented in this chapter is to give inspiration and to look at renovation, demolition, and new builds with the possibility of reuse as a way to reduce embodied emissions. The point of these examples is to be optimistic about the future and look for possibilities instead of focusing too much on limitations. In this chapter, there has not been a large focus on the legal documentation and re-certification of the different example solutions. One of the reasons for this is that a lot is happening regarding reuse in the construction field both in Norway, in Europe and the world in general. There are many ongoing research projects on reuse, and procedures and new standards for reuse are being developed. The laws and regulations are also about to be changed, meaning that information on which reuse examples are feasible or legal could change very rapidly, making the information invalid for future readers.

3.3.1_ 2 Building

The building stands for 39% of the total embodied emissions of a project according to the data source.[42] In Figure 15, the percentage of embodied emissions for building elements 21-29 are shown.

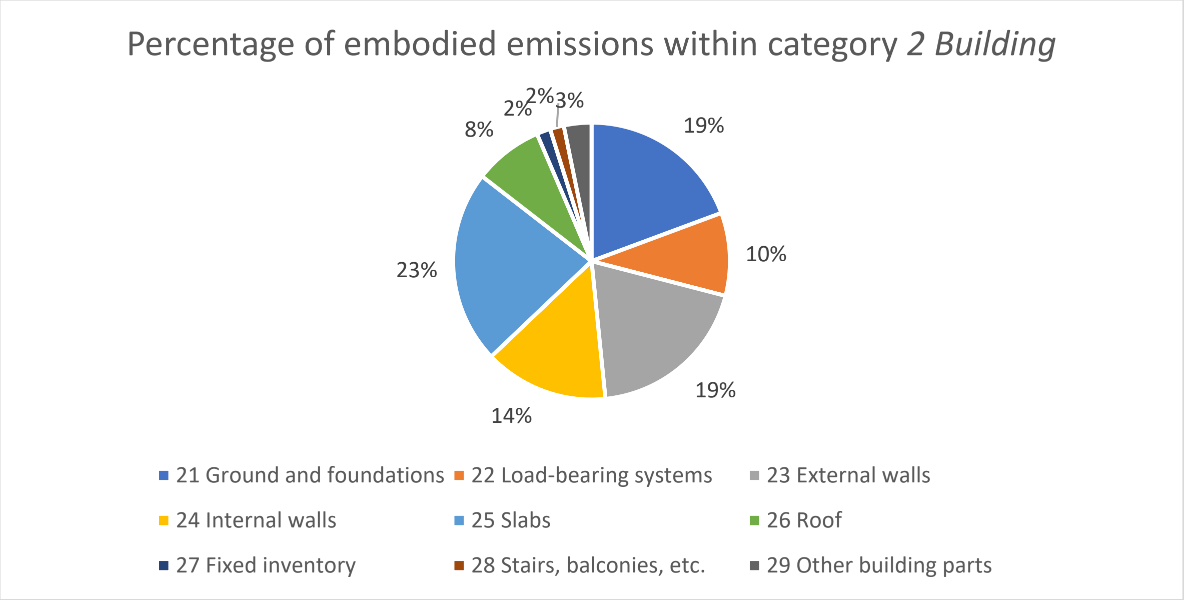


Figure 15 Pie-chart of embodied emissions within category 2 Building.

21 Ground and foundations

Ground and foundations stand for 19% of the building emissions.[42]

Foundations are typically not reused in demolition projects because it often entails that the new building will have the same placement and footprint as the existing foundation. Shallow foundations might have too low bearing capacity for the new construction and can therefore not be reused. Although there isn't a lot of room for reuse of existing shallow foundations today, designers and engineers should design for future reuse of new foundations being built.

Since the 1950's, it has become common to use pile foundations, especially on sites with clay ground. Since then, the cities have grown and we are building ever-taller buildings and structures. It is not sustainable for many generations of buildings to keep adding piles to the ground until all the space is taken up. Therefore, when a site that has existing pile foundation is to be redeveloped, the reuse of these piles has to be assessed.[43]

Figure 16 presents four different options in cases where there are existing pile foundations on site. The first option is to reuse the existing foundations so that they take the full load of the new structure. This can only be done if the new structure has a similar or smaller load compared to the original construction. It is possible to determine the bearing capacity and dimensions of the piles in several ways. The second option is partial reuse where the existing piles only carry part of the new structure's load. The third option is to leave the old piles in the ground without using them to hold the new load. This is an option with low risk, but the design of the new foundations must be wary of the location of the existing piles so that there will not be any collisions. The final option is to replace the existing foundations with new ones. This option is, however, both technically difficult and costly.[44]

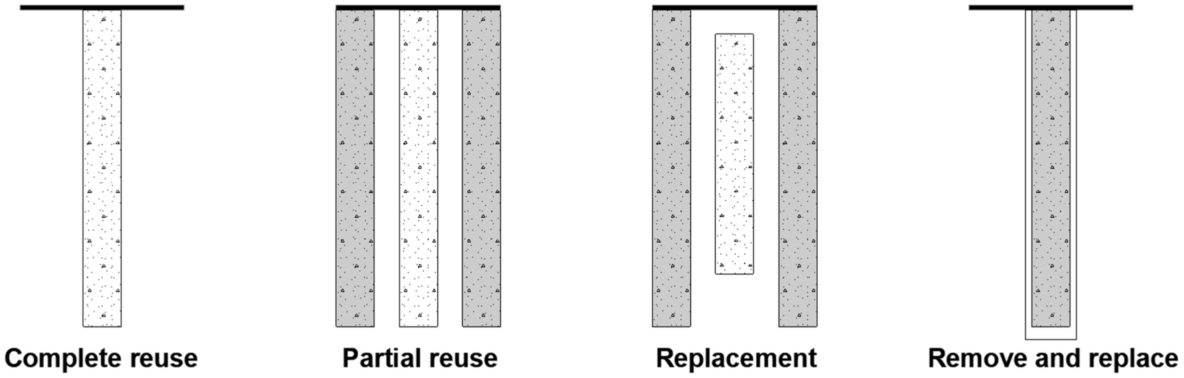


Figure 16 Four options when building on a site with existing pile foundation. (Illustration based on source nr. 44)

22 Load-bearing systems

The building element 22 Load-bearing systems includes, according to NS3451, separate load-bearing systems that are not an integrated part of the walls, roof or slabs. This can entail frames, columns, beams, bracing and fireproofing of the load-bearing structure. The main materials for these load-bearing structures are steel, concrete and wood.

Steel and aluminium

Metals like steel and aluminium require a lot of energy to be produced resulting in high embodied emissions but are on the other hand resistant and have a long lifetime. Often, metal components that have no cracks or bends have the same properties as a new component. It is favorable to reuse metal components where possible, since they have high embodied emissions in both the production phase and when they are recycled, as shown in Table 6.

Table 6 Embodied GHG emissions for virgin steel, recycled steel and reused steel.[45]

	New steel	New steel from 100% recycled steel	Reused steel
kgCO_2e/kg steel	2,8	1,35	0,24

Steel components like beams and columns are fit for reuse as long as the components haven't deformed or there is sign of corrosion. Another point to look out for is if the construction steel has been painted with paint that contains toxic substances. For some of these toxic substances, the problem can be solved by sandblasting the paint off or by painting over the toxic paint. However, some types of toxic paint will make a steel component illegal to reuse. Steel beams and columns are mostly produced in standardized dimensions and profiles and have bolted connections, making reuse easier. Construction steel produced before 1970 is generally not recommended for reuse.[45, 46, 40]

Concrete

Reuse of concrete elements is a possibility, mostly with prefabricated concrete elements. Today, concrete constructions are rarely built with design for disassembly in mind. In today's practice, it is normal to cast in place the different concrete elements to each other, which makes dismantling of concrete columns and beams rarely an option.[46]

Wood

Various wood elements are seen fit for reuse as long as the timber's original quality can be documented, and dismantling is possible. Construction timber elements such as trusses and beams can be reused. The load-bearing strength and firmness of timber is generally preserved well over time as long as the timber has no signs of rot or humidity damage. During the demolition work, it is important not to strain the construction element or apply unnecessary load, since this can damage the firmness of the timber. Also, glue-laminated timber used for columns, beams and other construction elements can be reused.

Normally, wooden construction elements are connected mechanically through nails, screws and staples, making dismantling easier. The benefits of reducing emissions through reuse are smaller for wooden elements compared to the benefits of reusing concrete and steel.[46, 40]

23 External walls

External walls stand for 19% of the building emissions.[42]

In the doctoral dissertation of Anne Sigrid Nordby, *Salvageability of building materials*, the author compares 10 different exterior wall construction types and looks at their embodied emissions. The results of the calculations are presented and compared in an environmentally justifiable lifetime. One lifetime is set to 50 years and is based on the embodied emissions of a wood framework wall with mineral wool insulation, a typical wall construction for Norwegian dwellings. The result comparison between the different wall types does not only show the large difference in emissions for different construction material types but can also be used to highlight which materials should be focused on regarding reuse.

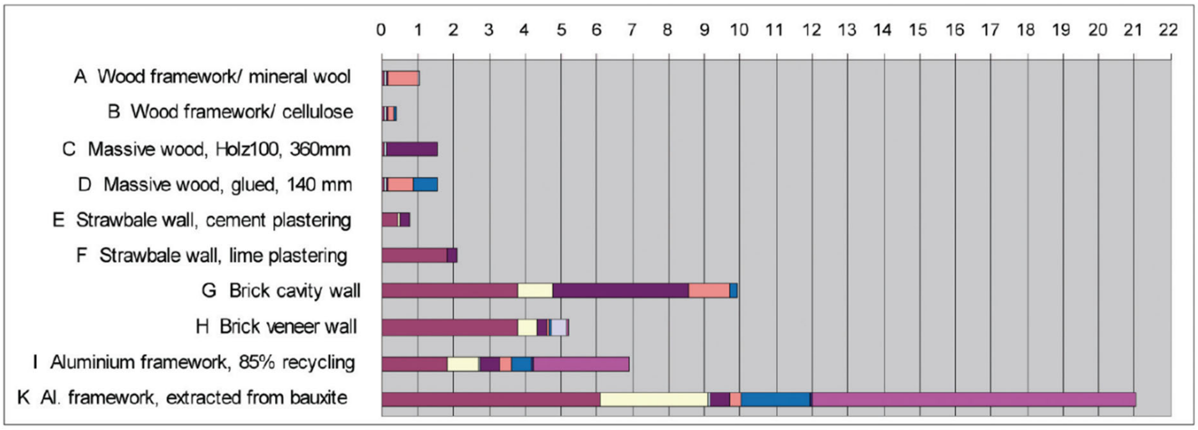


Figure 17 Environmentally justifiable lifetime for 10 different wall constructions.[47]

The results, shown in Figure 17 above, show that the wood framework construction is a low impact construction compared to brick and aluminium. A brick wall should be expected to have a service lifetime of 5-10 generations, which is obtainable for the brick material itself. The aluminium construction that is extracted from bauxite is expected to have a lifetime of 21 generations in order to be environmentally justified, which corresponds to an astounding 1050-year lifetime.[47]

Clay brick

Clay bricks require a lot of energy during production and therefore have large embodied GHG emissions, but in return, bricks are a versatile, strong and durable construction material. The service lifetime of a brick in itself can be up to several centuries. According to statistics from SSB on construction waste (appendix A.), bricks, concrete and other heavy building materials account for 60% of all waste produced from demolition projects.[47]

Table 7 presents the achieved reduction of GHG emissions from using different types of reused bricks compared to using new bricks. The reduction in emissions is calculated through LCA of lifecycle stages A1-A4. The emissions for transport in the assessment consider transport to the Oslo region of Norway. The results show that the embodied emissions are reduced by 84% when importing reused bricks from Denmark, compared to importing new bricks. When importing reused bricks that have gone through a combustion treatment in Denmark, the emissions are reduced by 27%. The best case in order to use bricks with the lowest embodied emissions is by using reused brick from within Norway that has not gone through a combustion treatment. This option decreases the emissions by 99%.[45]

Table 7 Reduction in GHG emissions of different types of reused bricks compared to new bricks. These numbers are made from LCA calculations of lifecycle stages A1-A4 of the products.[45]

	New imported clay bricks	Reused brick imported from Denmark	Reuse through combustion treatment in Denmark	Reuse within Norway without combustion treatment
Reduction of GHG emissions compared to new bricks	0%	84%	27%	99%

Clay bricks are well suited for reuse and as mentioned have a long service lifetime. One important factor to the reuse potential of bricks is the type of mortar that has been used around them. If the bricks have been constructed using cement mortar, the process of disassembly and reuse becomes much more labor intensive and difficult. Cement mortar is very strong, which makes it nearly impossible to disassemble individual bricks. The only solution is to saw out block segments of the old brick construction and thereafter do further work in order to get a reusable product in the end. Bricks in these cases are most often upcycled into new products instead of reused in their original form. Examples of upcycled clay bricks is exterior cladding and interior floor tiling. Nearly all brick constructions from before approx. 1925, and in fewer cases between 1925-1955, have been constructed using lime mortar. This mortar type is a far weaker connection than the cement mortar, making the disassembly for reuse of individual bricks easier.

Other important factors to consider are that there are no dangerous substances on the reused bricks and if they are frost-proof. Usually, bricks that have been on the exterior side of a wall are often frost-proof. If the bricks collected from a demolition do not meet the technical standards, they can for example get a combustion treatment. This is an energy demanding process but will restore the bricks to the same standard as new bricks.[40]

<u>Steel</u>

Steel components like beams, columns and trusses are well suited for reuse. The same considerations to these components would apply as they are described in *22 Load-bearing systems*. Figure 18 shows the exterior wall in the project KA13 in Oslo. The project has utilized a reused steel structure and reused bricks for the new exterior walls, while reused hulled prefabricated slabs have been used in some of the floors of this new project.[48]

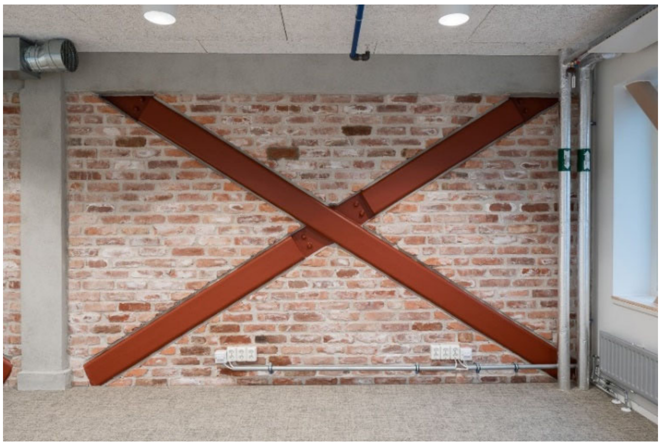


Figure 18 Reused steel structure and reused bricks were used for the exterior walls in the project KA13 in Oslo.[48]

Wood

Construction timber

Both exterior and interior walls can often be seen with construction timber studs. Timber studs can be reused in the same manner as other construction timber elements described in *22 Load-bearing systems*. Wood frame walls are one of the wall types with the lowest embodied emissions, as shown in Figure 17, and therefore, the benefits of reuse in order to reduce emissions are comparatively lower.

CLT – cross laminated timber

Walls made from cross laminated timber can be reused in their original form or be divided. If the element is part of the load-bearing structure, the thickness of the element should be preserved. If the thickness is altered, the load-bearing performance has to be documented for the new cross section.[40, 53]

CLT elements are often produced as customized components with various sizes and premade window and door cut-outs. This makes the generality of these components very low, meaning they give little room for architectural flexibility when reused. These large and specialized components can be used to reconstruct the same building. Although special equipment like a crane is needed in order to disassemble these large elements, as long as the connections are mechanical, it is relatively easy to reuse these elements.[47]

GHG in the different wall systems

In this section of the thesis regarding exterior walls, special focus has been given to the various construction materials of walls. The building element 23 does however also include insulation, cladding, vapor and wind barriers and other parts that can be part of the exterior wall.[19] In general, it can be said that the majority of the embodied emissions of an exterior wall lay in the main construction material. The GHG emissions for two different wall types are presented in Figure 19, in order to highlight the difference of importance between materials.[47]

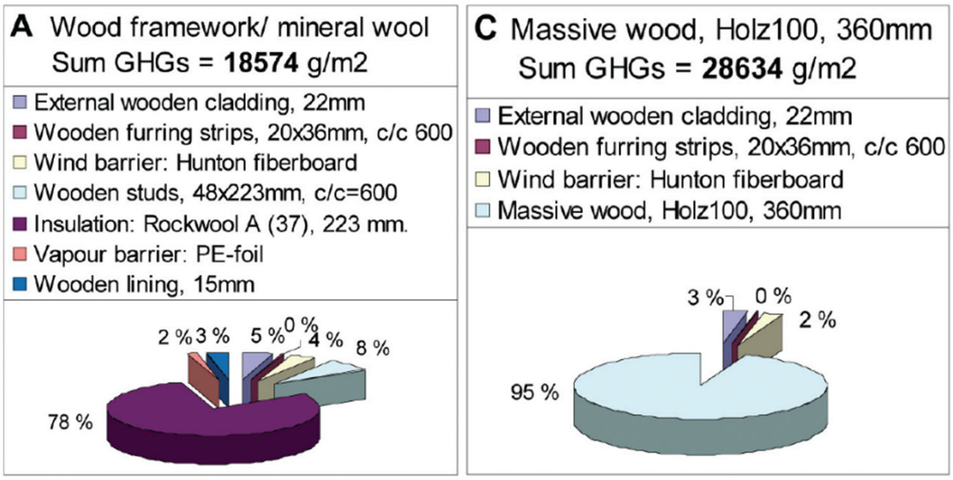


Figure 19 Embodied GHG emissions calculated for two different wall types: wood framework with mineral wool insulation and a CLT wall with 360 mm thickness.[47]

Windows and doors are also a part of building element *23 External walls*. These have not been included in the calculations shown in Figure 19. The reuse of windows and doors will be discussed in the next subchapter regarding building element *24*.

24 Internal walls

Internal walls stand for 14% of the building emissions.[42] Interior walls are typically constructed using timber stud frames or thin profiled steel. Typical wall finishes are gypsum boards or various wooden board products.

Gypsum is a large part of construction waste. As much as 7% of all waste in new builds is from gypsum (appendix A.). Gypsum boards can be reused as long as they are demounted without damages. If the boards are not fit for reuse, they can be recycled into new gypsum boards.[46]

Glass interior walls

Glass is a material with high embodied emissions. Therefore, the reuse of interior glass walls is of interest. Glass interior walls are often used in office spaces. The glass walls can have various traits regarding sound insulation properties or fire resistance. In order to be reused, the state of the glass wall must be assessed. This assessment should include the state of the window frame and window seals. If some of these components are worn or damaged, they can be changed. Glass walls and aluminium frames that have been in normal room climate throughout their use, do not age. Rubber seals and other plastic parts of the windows can, however, become brittle with age. If the windows have a wooden frame, more periodical maintenance is required, such as repainting.

A problem when reusing glass interior walls is that older wall elements used thinner glass than what is used in modern glass walls. The reason for using thicker glass today is that the technical requirements have become stricter over time. Harmful chemicals are rarely found in glass interior walls.[49]

Concrete walls (fire escapes)

In some instances, prefabricated concrete walls are used in stair shafts. They are used to provide fire-safe exit staircases and at the same time provide stiffness to the building structure (higher tolerance for horizontal loads).

Reusing a concrete stair shaft requires some consideration in order to fit into the new building design. Fire escape shafts are, however, quite simple and general in their design since they always aim at solving the same tasks. Therefore, they are considered of interest for reuse.

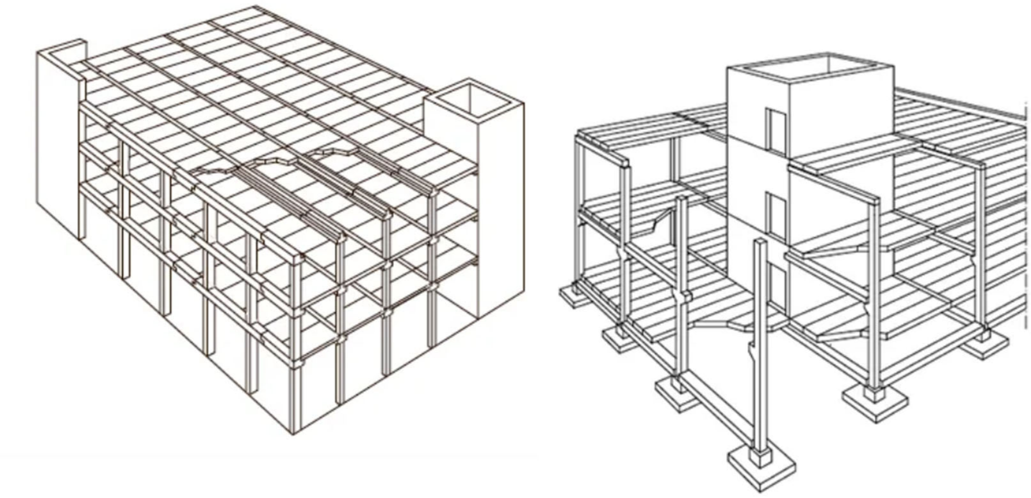


Figure 20 Prefabricated concrete wall elements used as stair shafts and as part of the load-bearing structure.[50]

Brick walls

In some cases, sourced reused brick might not meet all technical standards in order to be used on the exterior of the walls (not frost-proof) or they are not fit to use as load bearing structures. One solution is then to use the bricks as non-bearing interior walls as a way to increase the thermal mass of a building. Increasing the thermal mass is sometimes a favorable measure that can decrease the energy need for heating and cooling in a building.[40]

Windows and doors

Glass is a material with high embodied GHG emissions; therefore, it is interesting to look at the reuse potential of windows and glass doors. Windows and doors are mainly standardized products that are expensive, two factors that make them more likely to be reused. Windows and doors are also easy to demount during demolition or rehabilitation.[40] Windows typically have a lifetime of 20-60 years and they age due to exposure to sun, wind and rain. Windows are part of the exterior building barrier against climatic conditions. Therefore, it is important that they meet the technical qualities for U-value, rainproof and wind resistance. Due to all the technical requirements, exterior windows and doors usually do not get reused for their original purpose. There are more examples to be found where reuse of these products involves a change of use (for example from exterior use to interior) or upcycling to a new product. [40, 44]

25 Slabs

Hollow core prefabricated slab

Hollow core slabs are prefabricated elements that are often produced in standardized sizes. Another positive attribute is that they are more lightweight than other prefabricated concrete elements. All these characteristics, combined with a long service lifetime and high embodied emissions make them very interesting for reuse. When installed, the prefabricated elements get joined using in-situ casted concrete in the joints between the elements. In addition, the norm is to cast a thin layer on top of the prefabricated slabs. This top casting can vary in concrete quality and may or may not include different types of reinforcement. Different concrete qualities in the joints and on top of the slabs, as well as the thickness of the top cast, affect the needs for processing in order to reuse the hollow core slabs. Reuse of hollow core slabs is possible but requires processing of removing the surrounding casted concrete before reuse.[45]

CLT

The same principles apply when reusing CLT floor slab elements as when reusing CLT wall elements, described in the subchapter *23 External walls*.

26 Roof

Roof tiles have a long tradition of reuse. This is especially true for traditional slate roofs but also for clay roof tiles. Both slate and clay tiles are generally seen as fit for reuse as long as they aren’t damaged. Slate tiles can also be reused as cladding material.[46]

For reuse regarding structural components in the roof construction, generally the same information applies from the subchapters for building elements *22-24*.

27 Fixed inventory

Fixed inventory only accounts for 2% of the emissions for building element category *2 Buildings.*[42] Although the environmental benefits aren't as significant as for other components, the reuse of cupboards and kitchen cabinets is possible. Fixed kitchen parts are often replaced before their actual service lifetime is over, due to fashion fluctuations. For sustainability reasons this is an unfortunate trend, but on the other hand it creates a market where it is possible to find many kitchens that are fit for reuse.[41]

28 Stairs, balconies, etc.

Concrete, wooden or metal staircases can be reused as long as they are in good condition and are easy to demount.[46]

3.3.2_ 3 HVAC installations

HVAC installations stand for 12% of the total embodied emissions of a project according to the data source.[42] Performing LCA calculations on the material emissions from HVAC installations is seldom done. Some HVAC installations are well fit for reuse.

31 Sanitary

Three sanitary object types have been identified as most fit for reuse according to the REBUS guideline.[49] These are sinks, toilets and bathtubs. These elements are relatively easy to disassemble and are large. In the perspective of the total embodied emissions of a building, these components do not account for a large amount of emissions, as shown in Figure 13.

Sinks can be fit for reuse as long as they don't have cracks that can cause water leakage. Some smaller parts of the sink might need replacement, for example the bottom valve. Various forms of maintenance can easily be done, for instance there might be a need to remove limescale residues or repair small cracks on the porcelain surface.

When thinking about reusing toilets, one important characteristic is the flush volume. Toilets produced before the year 2000 have a larger flush volume of 6-9 liters, while today's toilets flush clean with 2-4 liters. Therefore, the material rewards of reusing an older toilet must be put against higher water usage.[49]

32 Heating

The reuse of radiators is possible. The main types of radiators that will be discussed for reuse are cast iron radiators and sheet steel radiators. Within sheet steel radiators, there are some newer radiators made of stainless steel and others from aluminium.

When thinking about reusing heating radiators, one aspect is if the component is in a fit condition for reuse, without rust or leakage problems. Another point to think of is the nominal power of the radiator, which together with the power requirement of the potential new space determines the sizing of the radiators.

The different materials give the radiators different desirable traits. For a modern, well insulated family house it might not be a good fit to choose a cast iron radiator due to its thermal inertia causing a slow rise in temperature. Aluminium on the other hand, conducts heat well, which means the radiator heats up to the desired room temperature very quickly.[51, 52]

Element *32 Heating* doesn't greatly affect the overall material emissions (Figure 13). When debating whether or not to use a reused "technical" component, material emissions should be weighted against operational energy need and indoor comfort.

36 Air treatment

The REBUS reuse guideline identifies ventilation ducts as suitable for reuse. The building element *36 Air treatment* stands for typically four times the amount of material emissions as *31 Sanitary* and two times the emissions of *32 Heating*.[42]

Round ducts come in standardized diameters from Ø63 to Ø1250 mm. The ducts are made from galvanized steel and are normally easy to disassemble. Ducts that are flexible are not often suitable for reuse, therefore this part focuses on stiff ducts and duct parts. Older ducts made from eternit are also not fit for reuse due to asbestos. Duct insulation is also rarely fit for reuse. To reuse ducts that are compatible with new component parts, the reused ducts should not be from before the 1990s.[49]

Especially in rehabilitation projects it can be advantageous to reuse the existing ventilation duct system. In order to do so, the ducts should both be in good condition and have the desired dimensions for the new ventilation system. Rinsing the old duct parts and reusing them on site is found not only to lower the material emissions but also more than halve the cost compared to installing a new duct system.[53]

Other parts with a long technical lifetime that can be fit for reuse are duct dampers, regulating parts, valves and diffusers.[49]

*Figure 21 Round duct, duct parts and duct damper. Photo: SINTEF Community.**Feil! Bokmerke er ikke definert.***

3.3.3_ 7 Outdoors

Building element *7 Outdoors* stands for 26% of the total embodied emissions of a project according to the data source.[42] The emissions connected to the outdoor space of a project are often not considered in an LCA. There is room for reduction of emissions, creative solutions and not least reuse in the outdoor spaces surrounding a building project. From the data on emissions presented in Figure 13 we can see that the emissions connected to element *76 Roads and sites* are especially large.

In the master thesis *Reuse of Materials in Landscape Architecture* by Even R. Krogh, there is a section presenting various examples of reuse, upcycling and recycling of wood, concrete, stone, metal and other materials.[54]

76 Roads and sites

The reason behind the often large, embodied emissions connected to the outdoor part of a building is due to the material choices of roads and site paving. Concrete and asphalt are often used in this area and there are very high emissions connected to these materials. Element *76 Roads and sites* includes roads (car roads, bicycle roads, pavements, walking paths), sites (parking sites, playgrounds) and outdoors signs.[55]

Pavers and slabs obtained by transforming concrete construction elements may be suitable for various outdoor applications: landscaping, building surroundings, roads and public spaces. Concrete constructions can be cut into slabs or pavers and be used as a paving product. The difference between a slab and a paver lays on their dimensional aspects. The different types of concrete constructions that can be used to make slabs and pavers are: interior walls cast in place, prefabricated panels or compression slabs on a shuttering slab floor system. The two main aspects to look in identifying suitable source elements is the concrete thickness (in general recommended to be minimum 60mm), little or no reinforcement in the concrete is desirable as well as the surface condition and the logistical considerations.

Figure 22 Irregular shaped fragments of demolished concrete from a residential building built in 1959, being reused on site to cover the ground of the outdoor spaces. Clos Saint Lazare in Stains, France, 2017.[56]

The pieces of concrete that have been selected after the demolition will require treatment of the edges, as well as cutting them into a desired shape and size. Concrete fragments with irregular edges may resemble natural stone paving as well as reduce the work on transforming further the fragments. Another option is to cut the original elements into orthogonal slabs and pavers. In addition to treating the edges, there might be a need for additional treatment of the concrete. Various surface treatments for concrete are possible although probably the most desired outcome in this case is to reduce slipping. Aesthetic reasons can also lead to decisions around surface treatments. Another optional action is a porosity treatment. This treatment involves the application of a pore filler in order to reduce the risk of deterioration from water.[56]

Figure 23 Reused granite and orthogonal slabs from demolished concrete used as outdoor ground covering in Pilestredet park, Oslo. (Photo: Helge Høifødt)[57]

Big granite stone blocks can be used for a large variety of tasks. They can become outdoor seating, retaining walls, walls for flower beds, stairs or as a frame for a water feature.[54]

The reuse of cobblestone is far more commonly practiced than the reuse of concrete. On the SINTEF report on reuse of cobblestone the main finding is that cobblestones are well suited for reuse and largely keep their material qualities over time. Other findings from the report are the vast reduction of embodied material emissions when reusing cobblestones as opposed to new cobblestones. On the other hand, it was calculated that the price for reused cobblestones is 30-50% more expensive than buying new cobblestones, depending on the size.[58]

Table 8 Variance in material emissions and price for reused and new cobblestones depending on the stone size. The values are the calculated averages of the result finding of the SINTEF report on reuse of cobblestones.[58]

Type of cobblestone	Material emission (A1-A5)	Price
	$kgCO_2e/m^2$	NOK
Old small cobblestones	4	2400
New small cobblestones	72	1800
Old large cobblestones	5	3400
New large cobblestones	83	2200

Figure 24 Reused cobblestone used in gutter for the houses in Telthusbakken (left) and outside Paulus church (right) in Oslo. Photo: SINTEF [59]

Other materials that are fit for reuse as outdoor paving are clay pavers, concrete pavers and masonry bricks. Reclaimed pavers are mainly used for exterior paving, for applications subject to moderate stress (pavements, pedestrian areas, squares, alleys, etc.) or more intense (roads suitable for motor vehicles, car parks, etc.). They are also suitable for other applications such as retaining walls, quays, stairs, etc., as well as interior flooring and roof terraces.[60]

Reclaimed clay pavers

Reclaimed concrete pavers

Reclaimed masonry bricks

Figure 25 Reclaimed clay pavers, concrete pavers and masonry bricks are well suited for reuse.[60]

3.4 Project examples

3.4.1 KA23

Kristian Augusts gate 23 in Oslo is a comprehensive renovation project realized in 2019-2022 by the real-estate company Höegh Eiendom in collaboration with FutureBuilt, Seltor, Arcasa and Multiconsult. The building was originally built in 1950 and was designed by the architects Bjercke and Eliassen. The building is 8700 m^2 divided between 8 floors. In addition, the exterior façades of the building are listed for architectural preservation.[61]

The project was a pilot project for FutureBuilt's circular buildings criteria version 1.0. The renovation project therefore aimed at 50% of the materials and building components being reused or reusable. At the same time, the project aimed at keeping the building's unique architectural details and qualities. Although only the exterior façade of the building was listed, a lot of the interior character of the building was kept in place or refitted.

The real estate company Höegh Eiendom commissioned the building to get a reuse-mapping prior to setting the contractor firm for the renovation works. When the contractor firm was chosen, they were involved in calculating the price for the changes. The reuse-mapping took place in multiple site-visits with external reuse-mapper and technical professionals. There was no testing or redocumentation of components made.

In the end, the project achieved reuse of components and materials that derived internally from the project site. The renovation project also tracked and sold used material that the project did not need so it could be reused elsewhere. The project did, however, not go forward with using reused materials from outside the building site. The reason for this was that there was difficulty regarding the regulations, risks and competence in the field. There was an initial attempt to use reused materials from outside the building site, but it was decided not to continue with this plan although it would have contributed to a higher percentage of reuse in the project.

The project group also used LCA during the design phase in order to choose new materials with low emissions. In addition, the project had a target to reduce the emissions by 50% compared to a reference building. The initial project targets as well as the results achieved are presented in Table 9. All the targets for emissions and reuse were met and surpassed. [62]

Table 9 Initial project targets and results achieved in the renovation pilot project KA23.

	Initial target	Achieved result
GHG emission reduction	Min. 50%	66%
Reusability	Min. 20%	Approx. 50%
Reuse	Min. 30%	Approx. 80%

The project did not only focus on using reused components but also that the new materials added would be reusable. Material quality, reversible connections (easy demount) as well as documentation of the new components by adding QR-codes give way for future reuse.

The components that were reused are the façade, foundations, bearing construction consisting of in-situ concrete, exterior walls, windows, slabs, elevators, parts of the interior walls and some technical equipment. The façade and windows were preserved because they were listed for architectural preservation. Other elements that were reused internally in the project are interior details and materials such as dark wood interior paneling, terrazzo flooring, stucco lustro- treated walls and ceilings. These elements were reused due to their architectural design properties even though they weren't listed for preservation by the building authorities.[63] Almost all the elements that were reused came from within the building site. Some examples of external reuse are floor tiles used in the shower rooms, metal wardrobes and drying cabinets as well as bicycle racks.

Figure 27 The exterior facade and windows were retained due to being listed for architectural preservation.[64]

Figure 26 Open office landscape with the old concrete structure visible. ***Feil! Bokmerke er ikke definert.***

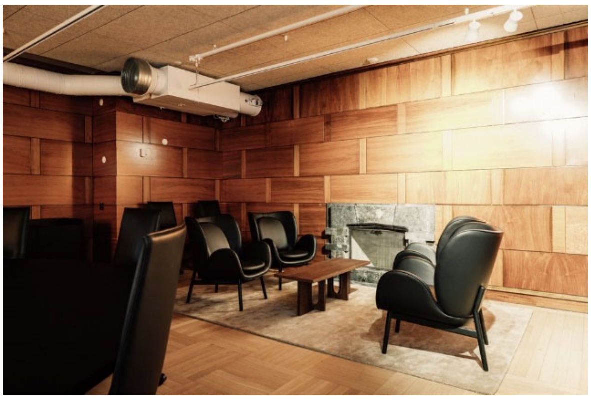


Figure 29 Interior wood paneling was reused to preserve some of the buildings unique character.[64]

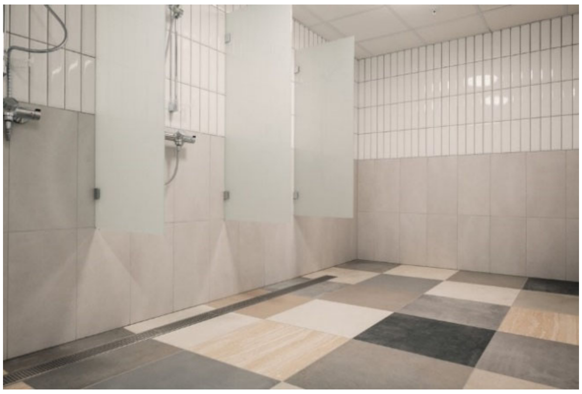
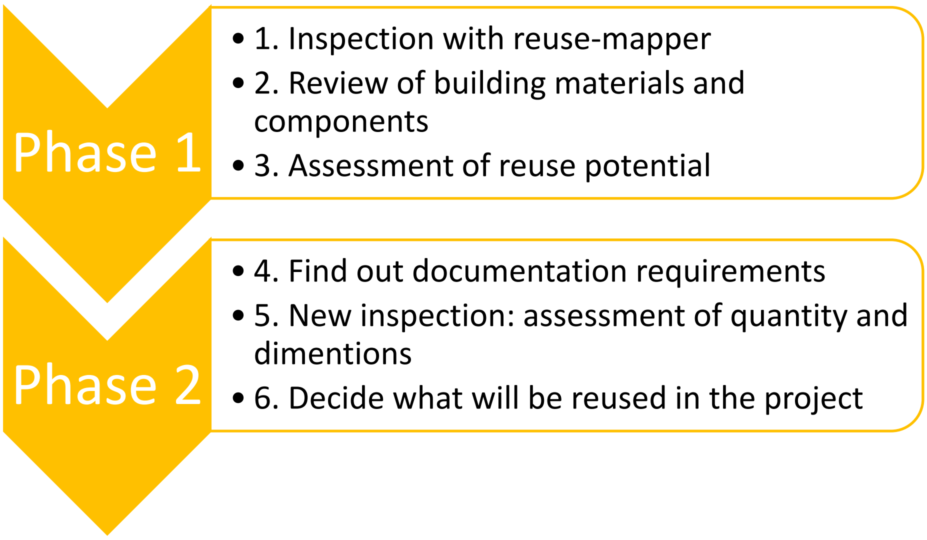


Figure 28 Reused floor tiles that were brought from outside of the building site.[64]

As mentioned, the goals for reuse were set to meet FutureBuilts' circular building v1.0 criteria. The focus from the beginning was to primarily reuse materials already available on-site. This decision was based both on the available material on hand since this was a rehabilitation project of an existing building and to avoid the required documentation for materials brought into the building from outside the project site. The work for achieving reuse in KA23 was possible with the help of reuse consultants and experts as well as good communication and cooperation across the work groups. The work was divided into two main phases. The workflow for each step is presented in Figure 30 below. To keep track of the materials available, their quantities and their reuse potential and other key information, a simple excel spreadsheet was used.



Phase 1

- 1. Inspection with reuse-mapper
- 2. Review of building materials and components
- 3. Assessment of reuse potential

Phase 2

- 4. Find out documentation requirements
- 5. New inspection: assessment of quantity and dimentions
- 6. Decide what will be reused in the project

Figure 30 The workflow regarding reuse for KA23.

Since KA23 was a pilot project, there were some key learnings from the process regarding reuse, the first being to start the process of reuse early in the project timeline. The second learning which was not initially fully planned, was the importance of documenting and marking all the components and materials. Initially it is important to mark the materials in order to clearly inform on what will be kept and reused, what can be disposed of and what is to be sold or given away for reuse on other projects. Since this project had both goals for current reuse and future reusability of the materials, documentation for maintenance and future renovations or demolition are important. In the end, Loopfront was chosen as a system provider to organize the documentation of materials and components in the building. Through Loopfronts' platform, the project team were able to make unique QR-codes that were attached to some components.

Although a lot of the material available on-site, not everything was needed for the refurbishment of KA23. The leftover materials and components were given or sold to be reused externally. This decision led to a 30% waste reduction for the project. Examples on materials and components that were given to external projects are 165m2 of ceiling boards, 130m of electrical wall channels, 8147kg of interior glass partition walls, interior walls and kitchens as well as 325000kg of brick.[64]

3.4.2 Cissi Klein High School

Cissi Klein High School is an ongoing new construction in Trondheim, Norway. The project work spans from 2021-2024. The school is planned to accommodate 700 students.[65]

The building owner is Trøndelag County (Fylkeskommune), as is normal for public high schools in Norway. The owner had a set of environmental goals for the project when it was listed for public procurement. Veidekke won the commission and is the primary entrepreneur firm for the project.

The project has been in its planning phase throughout the thesis work timeline. The project set out to achieve many environmental targets. The focus of this thesis is reuse, which was just one of the targets for the school building project. Other environmental targets are achieving ZEB-O and having an architectural design that follows the generality, flexibility and elasticity principles. The target for the embodied material emissions was set to a reduction of min. 45% compared to a reference building, where 5-10% of the reduction should be from using reused materials.

Table 10 Initial targets for reduction of embodied GHG emissions for Cissi Klein High School.

General reduction of material emissions	≥ 40%
Additional reduction through reuse	5-10%
Total reduction target	≥ 45%

So far in the planning phase, the project has not fully achieved the initial goals set for reduction of emissions through reuse. Since the project is in a relatively early stage, it is not possible to conclude the end reduction of emissions through reuse that the project will achieve. The planned reuse for the project at this moment indicates that the initial targets for reuse will be changed since it has been more difficult to achieve than expected.

It is of interest to look at what factors helped the reuse planning and what would have made it easier to achieve more reuse in order to meet the initial goal.

Since this is a new build and none of the existing materials on site were deemed fit for reuse, the Cissi Klein project relies on reusing materials from donor buildings outside of the building site. As shown in subchapter 2.4, the requirements for documentation are stricter when the reused materials are sourced from outside of the building site. The second challenge is finding donor buildings with materials that are fit for reuse and that have enough materials for their next use. Cissi Klein High School is planned to be a relatively large building of more than 14000 m^2 interior floor area. This makes it more challenging to source enough reused material to, for example, cover the whole exterior surface of the building. Finding donor buildings can also prove difficult in itself and the timelines of the demolition and construction phases have to be worked out together.

Since the project is owned by a government agency, there are also some added legalities surrounding purchases that have to be met. With little or no prior experience with reuse in building projects, it naturally takes more time to plan and create workflows in order to achieve reuse. The industry does not have many established ready solutions for purchasing reused materials that have already been re-certified and prepared for use. This increases the workload for the entrepreneur, making large amounts of reuse even more challenging to achieve.

Some factors that did make reuse more achievable for this project is the collaboration with Trondheim Municipality's newly created reuse center. They provide storage and assure the re-certification of reusable materials from demolition sites.[66] Another factor that made reuse easier for the project was a company called Høine that specializes in reuse and upcycling of clay bricks.[67] They offer a series of finished products made out of reclaimed clay bricks and assist in re-certification of bricks by using standardized testing methods and facilities in Denmark. Høine has specialized in one material and its reuse potential and offers projects a finished product to the building site, taking care of transportation, sourcing of material, storage and re-certification depending on the client's needs. This is an example of how the industry can grow and develop towards a more circular economy and providing reuse solutions that do not add to the workload of the entrepreneur but rather resemble a more "new product" order.

3.5 Strategy plan for reuse

A strategy plan has been developed on the background of the information collected throughout the report work. The strategy plan has been organized as a flowchart that is presented in Figure 31. The flowchart has been chosen as a presentation method in order to visualize and collect all the different factors that take place in the process that a project might go through in order to realize reuse. The flowchart aims at being a tool to assist with the planning of projects, both renovation and new construction. The flowchart should not be seen as a definitive answer but more of a guideline on how the workflow might take place for the reuse work in a project.

The flowchart suggests that the starting point of the reuse planning should be setting reuse targets. These targets might follow the requirements set by FutureBuilt v.02 or BREEAM-NOR. If the requirements from FutureBuilt or BREEAM seem too comprehensive for the project, the targets can also be self-defined by the project group. It is better to set up realistic goals and achieving them than deciding to not include any reuse goals in the project planning.

The second step of the planning process is looking for reused materials. The material sources can be one or a combination of: materials available at the building site, donor buildings or reused retailers. If the materials are already available on site, it might be the easiest and most direct way to achieve reuse. In highly urban projects, lack of space can however create the need for temporary storage of the components and materials off-site although in most cases this can be solved on-site. A donor building can be a rehabilitation project or a demolition project. Using one or multiple donor buildings for sourcing reused materials requires added logistics work when thinking about storage, transportation and the different project timelines. Sourcing the materials directly from a reuse-retailer can reduce the workload according to what services the retailer can provide. In some cases, both material treatment, transportation, storage as well as documentation can be done externally by the reuse-retailer. Most of the work on the flowchart could be outsourced to reuse professionals and experts, making the process more effective. This is mostly possible today in Oslo, but the reuse industry is still very small but growing.

Regardless of where the reused materials are sourced from, there is a need to know what possibilities there can be and have ideas on what materials are better suited for reuse than others. At the same time, a focus on achieving the environmental goals of the project, which are often linked to LCA, and reduction of embodied emissions should be in mind while looking for reused materials. The combination of reuse and GHG-emissions presenting various solution examples has been presented in chapter 3.3 of the report.

The next step of the flowchart is inspection with a reuse-mapper. It is not crucial that the reuse-mapper is a hired expert but at least having one person in charge of tracking the materials within the project group can be beneficial regarding planning and organizing. A reuse-mapping is something that would take place either if the project site itself has materials or if donor buildings are used for the material sourcing.

When some potential reuse materials have been found, the next steps are to review these materials and components and then assess their reuse potential. Many factors play a role in the assessment of a reused material. In order to document and collect this information for each material and component, a proposed table is developed and presented in subchapter 3.6.

Timeline is also important to take into account while assessing if the material from a donor building can be reused in a project. When the donor building is planned to be demolished, will often not align perfectly with when the materials are needed in the new project. When sourcing from multiple donor buildings rather than one, there are even more timelines to take into consideration. It is evident that project timelines are one of the factors that complicate the process of reuse of materials deriving from donor buildings directly into another project.

A cost assessment is optional when deciding if a reused material or component should be chosen over a new product. The reality however is that cost is almost always taken into account in any project decision. If a reused product has a higher cost compared to an equivalent new product this doesn’t necessarily mean that the reused material should not be chosen. In this scenario the environmental benefits of reuse should be compared to the expense difference.

It is important to assess the dimensions and quantities of reused material available. However, it is beneficial to not have a rigid number for a minimum of m2 needed in the project. As an example, we can see in KA23 that only the changing bathrooms and shower rooms used reused tiles. The toilets of the rest of the project do not have the same reused tile. Accepting that there are different materials used throughout the building and even working architecturally to solve these problems will allow for more reuse to be realized. Again, the reused bathroom tiles in KA23 are a good example to use in the way that not all the tiles were of the same color, but this was not seen as an obstacle and therefore a non-uniform pattern was designed for the tiles to be laid in.

Other important information to consider when making an assessment of reused materials is to ensure the absence of harmful substances or the possibility of removing them and otherwise making sure that the materials are safe according to the TEK17 requirements for their new use.

After the review and assessment of the available reused materials has been made, the project group has to decide which reused materials they want to use in the project. The next step then is to organize and realize the reuse of the materials chosen. The amount of steps in order to realize reuse will vary between projects and materials. As described in some of the solution examples in subchapter 3.3, some materials might need treatment before being installed in the new project. These treatments can be removing toxic paint from the material surface, add fireproof paint or alter the dimensions to fit the drawing plans. There can also be more aesthetic reason to treat the material surfaces, in order for them to obtain a different texture, finish or even shape, as for example the concrete slabs that were cut to resemble natural paving stones from the solution examples. Other tasks that have to be planned in order to realize reuse is retrieving and transportation of the materials and components as well as arranging storage space for the materials if needed.

The next step is creating documentation for the future. This documentation is valuable not only for maintenance of the building but also facilitate for future reuse. Important information to add is: LCA data, expected service life, connection method, disassembly information, building placement, dimensions, quantities, is it fit for future reuse?, other material documentation (fire classification etc), picture, material code / unique QR-code. Adding the material code or a QR-code directly onto the building materials will make tracking easier for when people need to find the material information in the future. The documented information will make it much easier for future reuse to take place when the project building is going to undergo maintenance, rehabilitation or demolition.

The last step in the flowchart plan for reuse is to assess what reuse was carried through, reviewing the end results, and seeing if the initial set project targets have been achieved.

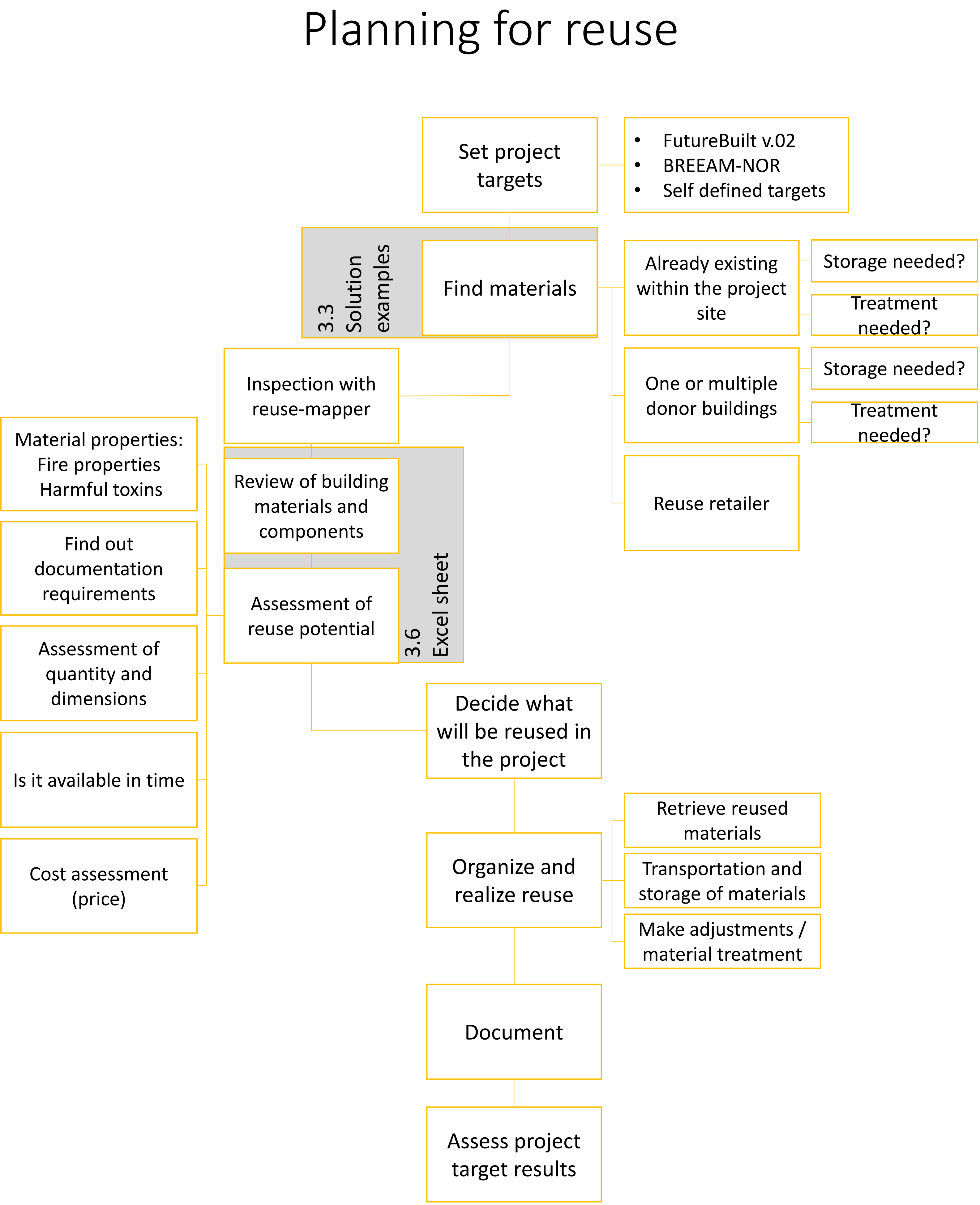


Figure 31 Flowchart for the planning process for reuse in building projects.

3.6 Review and assessment of reused materials – Excel sheet

Table 11 was developed to assist projects with documenting information in order to review and assess available materials for reuse. The table would be used during the reuse planning process where the project is planning on reusing materials already available on site or from donor buildings. This table could also be placed as part of the projects' environmental follow-up plan (Norwegian: miljøoppfølgingsplan or MOP) as an added excel sheet.

The table collects the most important variables that play a role when determining if a material or component can be reused in the particular project. Ofcourse, the table isn't definitive but more a starting point or guideline on how documenting this information could be done. Tables are easy to alter and customize according to the project needs. For example, a few of the table columns are only applicable and relevant according to if the material is sourced from within the project site or only if the material is sourced from a donor building.

Table 1 Tracking and documenting materials on existing building on project site or donor building.

Overview				Timeline	Quantity and dimensions					Material properties	
Building category	Material or Component	Description	Fit for reuse?	Planned demolition date**	Dimensions	m^2 available	(m^2 needed)	m^2 reused	m^2 to sell for reuse elsewhere *	Fire properties	Harmful toxins
Building element number from NS 3451	Example: Windows South Facade	For example: Year of production and other relevant information	Yes / Partially / No	Example: Dec 2023						Fire resistance class information if available	Yes/Yes but can be removed/No

Documentation	GHG-emissions				Cost assessment				
Documentation requirements	Reused product $kgC0_2e/m^2$	Quantity of reused material	Equivalent new product $kgCO_2e/m^2$	Savings in ghg-emissions $kgCO_2e$	Cost for material	Cost for treatment/adjustments before fitting	Total cost reused material	Cost equivalent new product	Cost difference
Must meet TEK17 requirements	Can use other measurements, for example kgCO2/kg of reused material	m2/kg/other		(reused product emissions per m2 - equivalent new product emissions per m2) * quantity of reused material	Price per m2 or total for the whole project	Add if needed /relevant	Cost for material + cost for treatment		Total cost reused material - cost eq. new product

* Rehabilitation / existing building

** Donor building

4. Discussion

4.1 Reuse in the building sector

The background findings indicate that reuse is one of the solutions to lower emissions in the building sector as well as reducing waste production. Although this report focuses on reuse, it is not a wonder-solution to all sustainability problems in buildings. The point is not to find the best solution for greater sustainability. In reality, the real solution is to implement as many aspects that contribute to reduction of emissions and raw material consumption as possible. The need for change throughout the whole industry, our practices and policies is urgent when trying to meet the targets set by the Paris agreement and the UN sustainability goals.

4.1.1 What is the current status on reuse in the Norwegian building sector?

Reuse in the building sector is currently a complex affair. There are many different factors that contribute to how much reuse is realistic to achieve in various projects. The general understanding of today’s situation is that there is a big “buzz” for reuse and it is becoming an increasingly popular concept. Despite the rapid growth of popularity for reuse, the industry hasn’t managed to meet the demand. The industry is not alone to blame here, since both standards, laws and regulations until very recently, mainly focused on new materials and was and largely still is heavily based on the linear economy perspective. Both the industry and national policies are changing, however if this change is happening fast enough is debatable.

The building industry is moving slowly into a more circular direction, with a few businesses focused on management and retail of reused building materials existing today. Most of the activity is surrounding the bigger cities, especially Oslo. A good example of an existing reuse-retail company is Resirqel which can assist projects with reuse-mapping, storage and re-documentation of materials. There is almost no industry for repairing building materials and components and preparing them for their ‘’new life’’.

4.1.2 Which barriers do current projects face when they want to realize reuse of building materials?

Today, choosing reused materials instead of new materials adds many more tasks to the entrepreneur firm and with this also added cost for planning. From the two project examples presented in subchapter 3.4 it is evident that it has been much easier to reuse in a renovation project than in a new build project. The reason for this is the previously existing requirement for documentation on all materials when they come from outside the project site. Therefore, reuse on site was up until recently the easiest way to achieve reuse. Today, the added workload of facilitating reuse in a project often ends up with the entrepreneur. The added tasks require time for planning and enough people to make out the logistics, recertification of products and mapping available materials and components. This added workload might stop or reduce the amount of reuse realized in projects.

In the ever-shorter project timelines it is important to account for the time it takes to accommodate for reuse. Grønn byggallianse asked in an interview with Jennifer Lamson from the KA23 project about her recommendations surrounding planning for reuse.[13] Her response is the importance of looking at reuse options from outside the building site as early as possible in the project planning. She explains that a project is like a machine that keeps moving forward where correct timing is important. Her second recommendation is to involve a professional reuse consultant throughout the project work.

Working and planning for reuse does not only demand time but also knowledge. When looking at donor buildings for a new construction or working in a rehabilitation project, the designers and project managers have to be able to see possibilities for reuse in the materials that are available and even be creative.

In order for reuse to become more widespread and normal there has to be an industry established. This includes experts for reuse for different materials, standardized workflows and a cost-effective market that works well with the project timelines. There is a need for more firms that have knowledge on correct demolition of buildings, can re-certify building materials, manage logistics, develop new products out of reused materials and sell them as a finished product. In this scenario, the entrepreneur does not have the responsibility to put in extra effort in order to realize reuse, they just have to order a finished product the same way they would do by ordering a new product. A few companies working with these solutions in Norway exist but there is a need for the reuse-industry to grow in order to make reuse something that we can see in a larger extend and in all projects, instead of only where there is a lot of motivation and high environmental goals from the owner's side.

One factor for realizing reuse that is not discussed earlier in this report is the difference in using reused materials in big projects vs smaller projects such as cabins or single-family houses. The larger the project, the larger the material quantities needed are. This can make reuse more difficult for large buildings compared to smaller ones. Uniformity and quantities of the same material from donor buildings is one side of the problem. The other is the added complexity in planning if there are multiple donor buildings. The timelines of each demolition of the different donor buildings and the new project itself will seldom align with each other. Factors that help this are if the timelines are longer, for example the demolition project can happen throughout a longer period of time or if there is a storage alternative for the materials that will be reused in the future.

Availability and access to reused materials are key to building up a circular economy. In the background theory of the report, it is presented that during 2020 a total of 2135747tons of waste was created from the building sector. There is however no statistics on how much of this waste could potentially have been reused in other projects. It would be interesting to see an assessment of how much reusable building materials there is in the Norwegian building stock. Norway is however a wealthy country with a very high consumption per inhabitant, which creates a lot of waste and has a bigger building stock. These are indicators that there might be a potentially large access to reused materials with more correct disassembly and demolition of projects.

Regardless of the high consumption per person, there is still need of a certain size of population in order to be able to create a usable reused retail market and services. How large can the radius of sourcing for reused materials be? How far are we willing to transport reused materials and components in order to have more to choose from? In the solution examples it is mentioned importing reused bricks from Denmark while the Cissi Klein case project has only chosen donor buildings within a 5 km radius from the building site. On the other hand, many of the new materials used in building projects in Norway have travelled large distances and are often imported from abroad. Why not also import reused materials too, since we are already importing so many new building materials from abroad? Can the added transportation emissions and cost still make reused materials sourced far away from the new project site a viable option? When projects reuse very locally, this also limits the reused materials available within the project timeline.

4.1.3 How can the result findings of the report help future projects with realizing reuse?

The result findings have produced three main tools to aid during the planning process for building projects that want to realize reuse of materials and components. These three tools are found in subchapters 3.3 Solution examples, 3.5 Strategy plan for reuse and 3.6 Review and assessment of reused materials.

What is apparent when looking at the flowchart for reuse in Figure 31, is that there are many factors that have to be taken into account as well as knowledge in order to realize reuse in projects. There is a lot of steps to think about and that require additional time and work especially during the project planning process. This is also the reason why in a project with larger amounts of reuse there might quickly be a need for a reuse-mapper either from inside the project group or hired externally.

The complexity of how a reuse plan looks today also emphasizes the advantage of choosing fewer materials and components with higher embodied emission reductions instead of many individual materials with low impact on reducing the embodied emissions and thereafter reaching the set goals of a project. This is where the result chapters 3.2 and 3.3 are meant to offer assistance. Chapter 3.2 shows LCA data on which building parts account for the highest embodied emissions generally in buildings. Then chapter 3.3 present solution examples on reuse to inspire and showcase reuse examples that can lead to higher embodied emission reductions. The chapter also shows through practical examples what factors and problems can arise when working with different material types. The negative aspects of the solution examples is that the example selection is somewhat limited, there are definitely many more examples of targeted reuse that could have been showcased and even smart solutions that we are yet to see in reference projects. The other negative aspect of the solution examples is that they mainly offer a qualitative assessment as opposed to comparing different solutions with qualitative measurements.

The tools created in the result part is something that is needed now and in the near future but is not a long term solutions. This is especially true for chapter 3.5 and 3.6. The tools developed aim at helping with planning for reuse in projects within the current situation of the industry. It is for a system where reuse is seen as an additional set goal for a project where the internal project group has to solve most of the added work connected to finding and reusing materials and components. In the future, hopefully the circular economy will have developed a whole industry for managing reused building materials, treating them and reselling them.

In a way, all three tools created all aim at helping to some degree to help achieve a more targeted reduction of ghg-emissions through reuse. This is the reason why an early assessment of ghg-emissions is included in Table 11 *Tracking and documenting materials on existing building on project site or donor building.*

4.1.4 What might the near future development for reuse in the Norwegian building sector look like?

There is a general interest surrounding reuse in the Norwegian building sector today, even if the amount of projects realizing reuse are few. Following the changes in regulations that came into effect in July 2022, the sale and reuse of building materials and components has become easier and simpler. It is however too early to say what impact the changes in government requirements will do to the amount of reuse we see in the Norwegian building sector. Will the development of circular businesses within the building sector accelerate and grow or will the development stagnate and take many more years to develop into something substantial enough to be able to call normal?

The government has taken a few big steps to encourage reuse and growth of businesses that work with reuse and circular economy. Now, the question is how the industry responds to these changes and if projects and retailers want to work with reused materials. Typically, the market and services available for reuse have to grow to a certain size throughout the country before new regulations on reuse can come into effect. A logical future advancement in the regulations would be a minimum requirement of reused or reusable materials in future projects. Requirements of this sort are not expected to happen in the near future since there is no established market for reused materials, something that will make it difficult for every single project to acquire reused materials. However, the probability of requirements regarding total embodied emissions in building projects will likely come in effect in few years. Therefore, government requirements on embodied emissions in general might lead to an increase in reuse as one of the methods to lowering project emissions. Another way the government can accommodate for more reuse is to create favorable tax-policies. Trondheim Municipality has gone forward and also created a storage facility for building materials that are fit for reuse. Stately and municipally owned buildings account for a large building stock in the country. These state organs are already and will probably continue putting reuse goals on their own building project as an initiative to support the growth of a reuse & repair industry.

4.2 The thesis report

The thesis report has, like any other report, both positive and negative qualities. The subject of reuse in the building sector can be seen as both narrow and broad, and it is difficult to know how in-depth the information should be or what must be left out. One side of reuse that was decided to not be a big part of the thesis was Design for disassembly and design methods for future reuse. Partly, this was decided to narrow the focus area of the report. Another reason for not including future reuse as a big part of the thesis is that there is greater uncertainty when saying how things are done in 60-100 years in the future.

One particular building element with high emissions was left out of the subchapter 3.3 Solution examples, that would be relevant to include in this study. This building element is *39 – Other HVAC installations*. Solutions for this building element were not included due to lack of sources regarding reuse of these elements.

It is important to have a perspective of where the biggest emissions lie in a building project. This can hopefully make the reuse process more targeted towards materials with higher embodied emissions. It goes without saying that more reuse almost always leads to greater reductions of emissions. However, today's reality shows that reuse takes a lot of time and planning to realize. Therefore, this report has hopefully managed to, to some extent, create a guideline for some materials and components that are more important to focus on when the goal of reuse is to lower emissions. The goal was that this would be useful knowledge to both project managers and architects in order to look for possibilities for effective reuse when working on projects.

The LCA data used in the report and presented in subchapter 3.2 was both good and bad. The largest collection of embodied emissions data for Norwegian buildings was used which is positive. Also, the data was presented by building element according to NS 3451, the same method that was desired for the presentation of project examples in subchapter 3.3 Solution examples. The negative aspect of the LCA data found was that there was little or no data available for some building elements. This creates an incomplete picture of where the emissions of a building lay. Hopefully, in the near future more source data from Norway can be collected for a more complete and accurate picture of the material emissions. All buildings are different and therefore the LCA data presented will not give an accurate description for particular buildings. In the end the result part of the report covers a lot of different building types instead of subdividing or focusing on different building types separately such as residential/non-residential or schools, office etc.

The result part of the thesis focuses on embodied greenhouse gas emissions and connecting it to reuse as well as create tools that can assist future projects in planning for reuse. The LCA methodology does, however, not necessarily only focus on greenhouse gas emissions. In reality, GHG emissions are not the only important indicator when determining the importance of reusing a certain material or building component. Other very important parameters are the availability of virgin material in nature as well as how recyclable the material is and if it comes from a renewable source. Another important parameter is if there are harmful substances and chemicals in the component. This can occur in older building materials and can lead to HSE assessments to be more important under demolition work.

The report focuses heavily on reuse today and does not look too far into the future. The reuse field in changing rapidly making the report more a ‘’picture of the time’’ where the findings are relevant for a limited time. For example, the tools developed in the result chapter can in few years no longer be needed in building projects if the reuse-industry takes over these tasks and makes the work more effective. This doesn’t necessarily mean that the findings aren’t important. Since there is little sources and previous research work on the topic of reuse it is even more important to try to collect, learn and develop tools that might take the industry one step forward. Reuse is evolving and we are not where we should be when thinking about the goal of Norway having a more circular economy in the near future.

5. Conclusion

The background research shows that there is a need for a more circular economy in order to mitigate climate change and meet the sustainability targets that Norway has signed to participate in. The building sector in Norway stands for a large amount of both material emissions and waste production. Looking at the waste hierarchy pyramid, the second most favorable solution is reuse of materials, which is also the chosen topic of the thesis report.

The thesis has aimed to gather all the different factors that affect the amount of reuse realized in today's construction sector. Prior to July 2022 the laws and regulations were only made to fit the linear economy as opposed to a circular economy. Previously the regulations demanded full re-documentation on reused materials that come from outside the building site. This made reuse in refurbishment projects much more obtainable than in new builds, which can also be seen through the two project examples in subchapter 3.4 of the report. Changes in the regulations did however come into effect from 1st of July 2022. The changes in regulations that make the retail of reused materials more easily obtainable were driven by companies wanting to grow a reuse market for building materials as well as the emerging focus on reuse in general.

The current status on reuse in the Norwegian building sector is that it is a relatively new branch within the building industry which is emerging but still very small in impact. There are very few companies and industry professionals that work only on reuse of building materials today. There are also few projects that set targets for reuse but some tools and experience exchange have started to happen, especially the past couple of years. A lot of research is also happening currently on reuse of building materials, like the REBUS research project. Reuse of building materials is a field that will see a lot of development in the form of an increase of available information and tools, in the near future.

The result part of the thesis looked at the connection between embodied emissions per building element and reuse and developing tools that assist with planning for reuse. Having targets for reuse in a project today often entails added planning, cost and expertise needed from the entrepreneur firm. There are few projects that actually achieve large amounts of reuse.

Through the work with the solution examples and project examples it became apparent that there are many steps and things to think about when planning for reuse. The flowchart in Figure 30 was used to collect and organize all the steps in order to assist future projects with planning for reuse. The complexity behind planning and realizing reuse in a project showcases the need for targeted reuse. Targeted reuse is a way to refer to reuse materials and components that account for relatively larger savings in embodied emissions.

Therefore, it is seen as useful to highlight some materials and components that when reused, have a larger contribution in lowering the material emissions. The results indicate that, as a rule of thumb, the materials that have high emissions in their production will also give the greatest reduction of emissions when reused. The most common materials that this is true for are steel (and other metals), concrete and glass. The LCA data showed the importance of the embodied emissions of other elements than the building itself. Both technical installations and outdoor elements are areas with large emissions that can also implement reuse as a way to reduce material consumption and emissions.

The findings of the report also indicate the need for more services and companies that specialize in reused building materials. If there are more finished “products” that are reused in the market, it would be easier for projects to achieve higher rates of reuse. The entrepreneur should not be left alone to do the job of logistics, recertification and planning for reuse. That is how it mostly is today. The chances of succeeding in a large amount of reuse are then smaller. In addition, if there aren’t enough external specialized companies providing these services and materials at a competitive price to new materials, the future of reuse in buildings will keep being reserved for developers with a special interest for reuse instead of the whole industry becoming more circular, which should be the end goal.

6. Recommendations for further work

The thesis report could have been structured differently and focused on some other aspects of reuse in the building sector. Some recommendations for other future work regarding the subject of reuse are described in this chapter.

The same thesis topic could be applied but with a focus on residential buildings. This could show greater opportunities for reuse in the current and near-future industry because there is a lower quantity of reusable material needed to be sourced.

Instead of focusing on residential buildings, the same thesis topic could be applied but with a focus on non-residential buildings. The typical materials used in non-residential buildings often differ from residential buildings. Therefore, there will be a difference both in the LCA data and material reuse suggestions than in a report that focuses on residential buildings. In addition, there may be other upsides and downsides on working with non-residential projects on reuse.

This thesis report didn't look into all the building element parts included in the NS 3451. This is especially true regarding the reuse of technical systems. It is interesting to look into the subject of reuse of technical systems and connecting this to data on emissions. This work will however have little previous research, making collection of data challenging.

The thesis could have taken a much more practical and "hands-on" approach to reuse of building materials and components. The research could be based on working with cases of multiple demolition sites and looking at the waste or recycle materials available. The report could also then look at creative possibilities for as many things as possible out of the materials that would otherwise end up as waste. The downside of looking at specific sites and projects regarding reuse/upcycling is that the opportunities for reuse and the materials available can vary greatly. Therefore, a report that has taken this approach might not gather a full scope of examples and results.

Design for disassembly and design methods for future reuse was not a very big part of the thesis. Another thesis could focus on just these subjects. For example, looking only at the connection between the different building layers could be a thesis in itself. This could be done for instance by looking at all the different layers of an exterior wall or slabs, showing the service life of each component, how each layer can easily be disassembled without having to destroy other layers and what the materials or components can be used for if their service lifetime is longer than the building lifetime.

Tracking what the Norwegian building stock is also relevant topic in the circular economy research. What reused materials will typically be available in the near future when looking at typical demolition projects? Are there ways to quantify certain material types or are the building materials and component too specialized and varied for such research? More importantly, is there data any data to be found on this topic or would it have to be created? One of the ways to work with this topic could be through working with demolition companies.

Reuse in the building sector is an emerging and relevant topic. The rapid changes that are both in effect but also in need in order to meet the international sustainability targets create a continuous need for new research and work. Lastly, it is important to mention that all topics regarding sustainability in the building sector are important and relevant for shaping the future development of this industry.

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Appendices

A. Table of waste production in the building sector per material category presented in both tons of waste and percentages.

Source: Statistisk Sentralbyrå. Genererte mengder avfall fra nybygging, rehabilitering og riving (tonn), etter materialtype [Internet]. Norway: SSB; 2020 [2022 Mar 08]. Available from: https://www.ssb.no/statbank/table/09247/

B. Embodied greenhouse gas emissions in Norwegian buildings. Relevant data and graphs from ZEN Report No.24.

Source: Wiik MK, Selvig E, Fuglseth M, Resch E, Lausselet C, Andresen I, Brattebø H, Hahn U. Klimagasskrav til materialbruk i bygninger [Internet]. Norway: The Research Senter on Zero Emission Buildings; 2020 [2022 May 01]. Report No 24-2020. Available from: https://fmezen.no/wp-content/uploads/2020/05/ZEN-Report-no-24_Klimagasskrav-til-materialbruk-i-bygninger.pdf

Statistikkbanken

Avfall fra byggeaktivitet

09247: Genererte mengder avfall (tonn), etter måleenhetvariabel, materialtype, statistikkvariabel, år og aktivitet

	Avfallsmengde			
	2020			
	Byggeaktivitet i alt	**Nybygging**	**Rehabilitering**	**Riving**
Tonn				
Materialtyper i alt	2 135 747	646 742	510 806	978 200
Treavfall	267 447	109 967	89 636	67 844
Papir og papp	22 110	13 915	6 222	1 974
Plast	11 204	6 808	3 423	973
Glass	11 130	3 796	5 510	1 825
Metall	116 981	24 058	33 405	59 518
Gips	78 714	45 894	24 936	7 884
EE-avfall	10 193	1 416	3 967	4 810
Farlig avfall	41 445	4 783	26 002	10 660
Farlig avfall. Oljeforurenset masse	5 419	1 866	1 350	2 203
Farlig avfall. PCB- og PCT-holdig avfall	591	0	474	117
Farlig avfall. Impregnert trevirke	12 526	0	11 063	1 463
Farlig avfall. Slagg, støv, flygeaske, katalysatorer, blåsesand m.m.	3 219	179	2 613	427
Farlig avfall. Asbest	6 028	0	2 446	3 583
Farlig avfall. Spillolje	996	677	301	18
Farlig avfall. Avfall med ftalater	2 611	197	1 107	1 306
Farlig avfall. Annet	10 055	1 864	6 649	1 543
Tegl og betong og andre tyngre bygningsmaterialer	865 325	113 848	170 024	581 454
Forurenset tegl og betong	197 528	9 932	35 387	152 209
Asfalt	201 255	190 171	7 135	3 949
Blandet restavfall	289 225	113 096	95 947	80 181
Annet avfall	23 189	9 058	9 212	4 918
Prosent				
Materialtyper i alt	100,00	100,00	100,00	100,00
Treavfall	12,52	17,00	17,55	6,94
Papir og papp	1,04	2,15	1,22	0,20
Plast	0,52	1,05	0,67	0,10
Glass	0,52	0,59	1,08	0,19
Metall	5,48	3,72	6,54	6,08
Gips	3,69	7,10	4,88	0,81

	Avfallsmengde			
	2020			
	Byggeaktivitet i alt	Nybygging	Rehabilitering	Riving
EE-avfall	0,48	0,22	0,78	0,49
Farlig avfall	1,94	0,74	5,09	1,09
Farlig avfall. Oljeforurenset masse	0,25	0,29	0,26	0,23
Farlig avfall. PCB- og PCT-holdig avfall	0,03	0,00	0,09	0,01
Farlig avfall. Impregnert trevirke	0,59	0,00	2,17	0,15
Farlig avfall. Slagg, støv, flygeaske, katalysatorer, blåsesand m.m.	0,15	0,03	0,51	0,04
Farlig avfall. Asbest	0,28	0,00	0,48	0,37
Farlig avfall. Spillolje	0,05	0,10	0,06	0,00
Farlig avfall. Avfall med ftalater	0,12	0,03	0,22	0,13
Farlig avfall. Annet	0,47	0,29	1,30	0,16
Tegl og betong og andre tyngre bygningsmaterialer	40,52	17,60	33,29	59,44
Forurenset tegl og betong	9,25	1,54	6,93	15,56
Asfalt	9,42	29,40	1,40	0,40
Blandet restavfall	13,54	17,49	18,78	8,20
Annet avfall	1,09	1,40	1,80	0,50

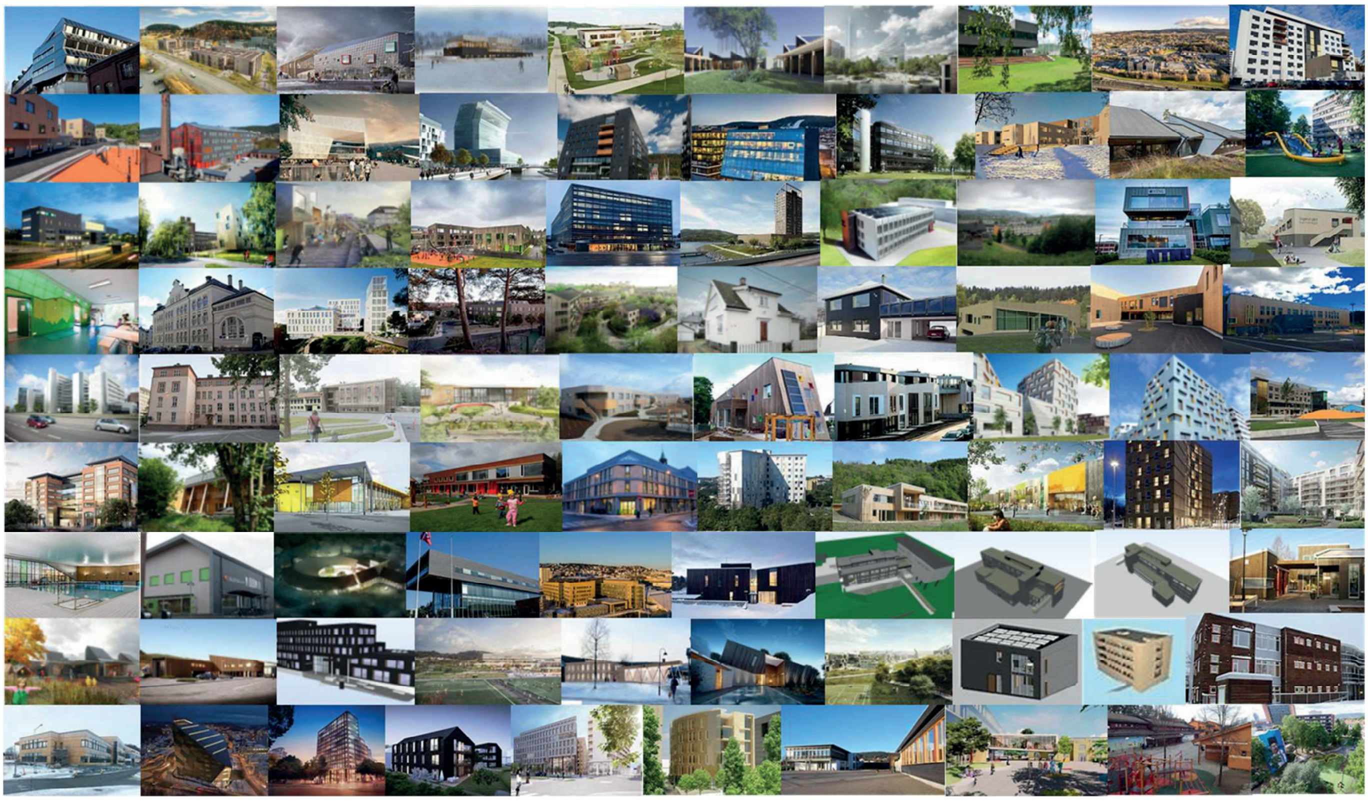
↑ Til toppen

Research Centre on
ZERO EMISSION
NEIGHBOURHOODS
IN SMART CITIES

KLIMAGASSKRAV TIL MATERIALBRUK I BYGNINGER

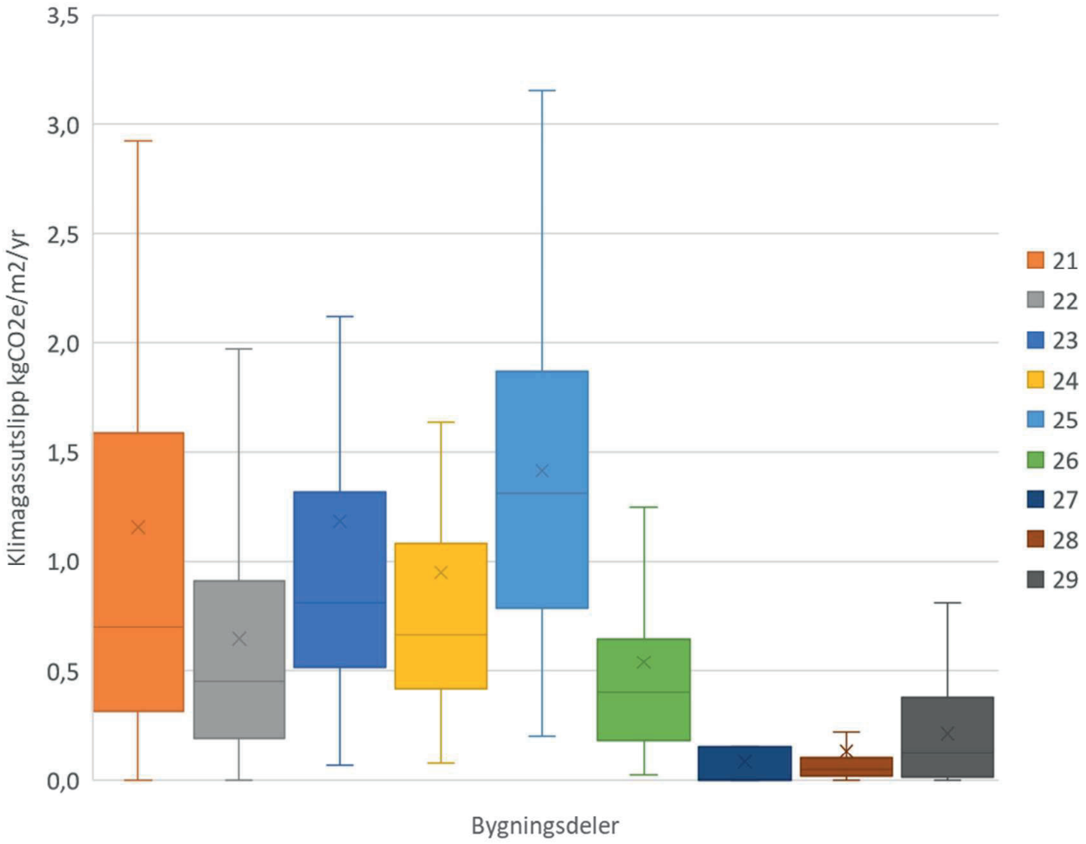
Utvikling av grunnlag for å sette absolutte krav til klimagassutslipp fra materialbruk i norske bygninger

ZEN REPORT No. 24 – 2020

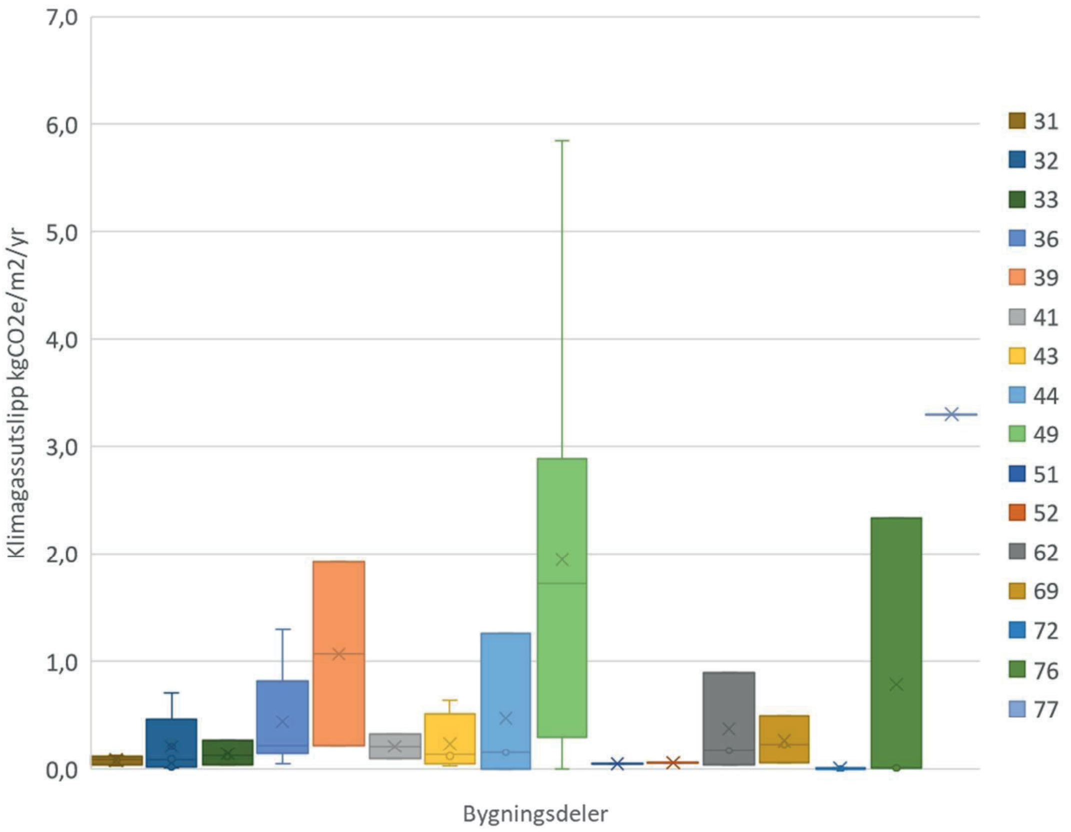


M. Kjendseth Wiik, E. Selvig, M. Fuglseth, E. Resch, C. Lausselet, I. Andresen, H. Brattebø, U. Hahn

SINTEF, Civitas, Asplan Viak, NTNU, Futurebuilt



Figur 15: Boksplott av klimagassutslipp (A1-A3 og B4) fra ulike bygningsdeler i som bygget fasen.



Figur 16: Boksplott av klimagassutslipp (A1-A3 og B4) fra ulike bygningsdeler i som bygget fasen.

Vedlegg B

Resultatene for statistisk analysen av bygningsdeler for alle bygningstyper (kgCO$_2$e/m^2/år). Resultatene ekskluderer rehabiliteringsprosjekter.

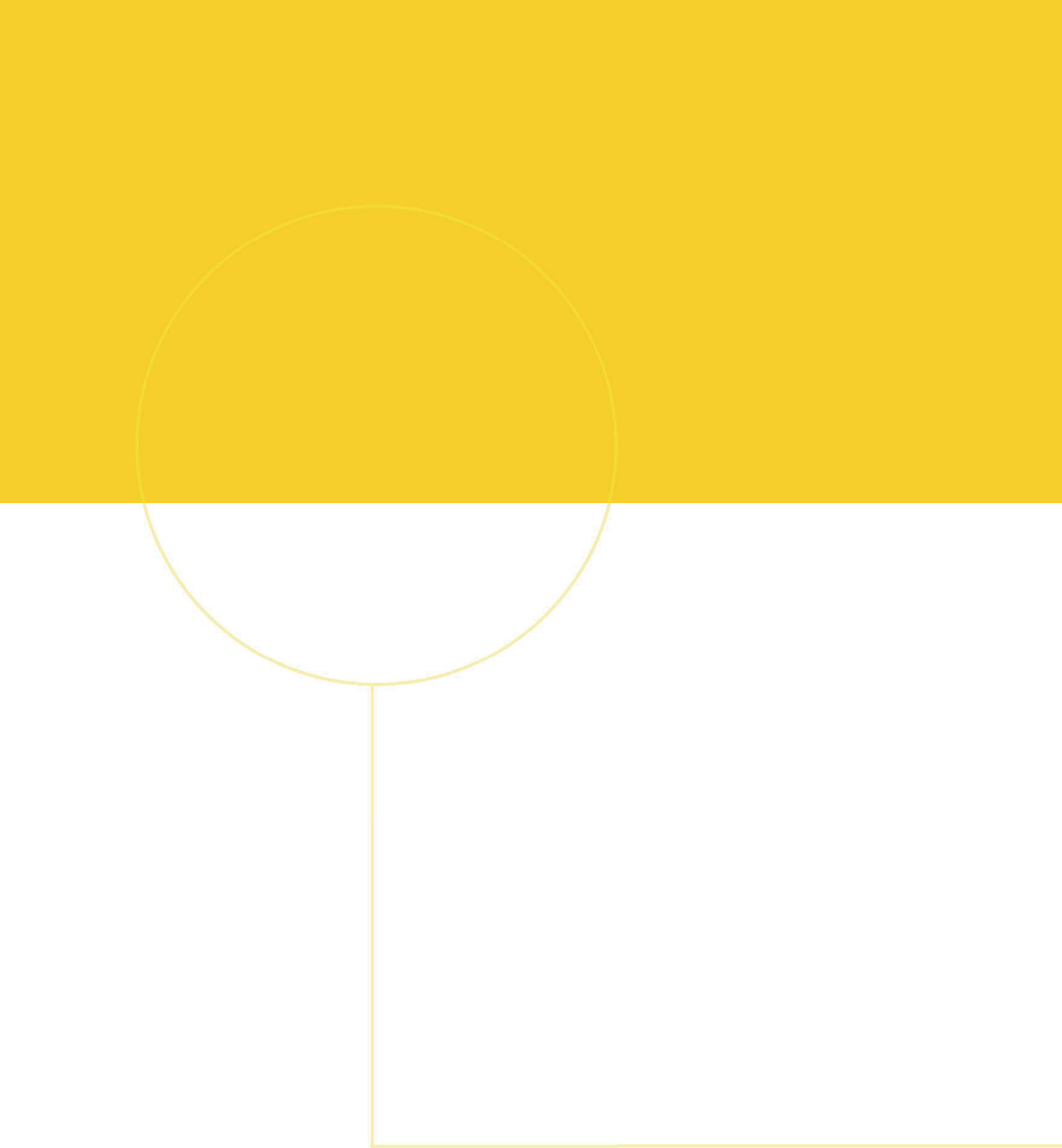
Bygningsdel	21	22	23	24	25	26	27	28	29	31	32	33	36	39
maks verdi	7,2	4,0	6,2	6,4	4,3	5,5	0,4	3,1	0,8	0,1	0,7	0,3	1,3	1,9
95. prosentil	3,5	2,0	3,4	3,2	2,8	1,5	0,3	0,4	0,7	0,1	0,6	0,3	1,3	1,8
75. prosentil	1,6	0,9	1,3	1,1	1,8	0,6	0,1	0,1	0,4	0,1	0,2	0,2	0,4	1,5
gjennomsnitt	1,2	0,6	1,2	0,9	1,4	0,5	0,1	0,1	0,2	0,1	0,2	0,1	0,4	1,1
median	0,7	0,5	0,8	0,7	1,3	0,4	0,0	0,1	0,1	0,1	0,1	0,1	0,2	1,1
25th prosentil	0,3	0,2	0,5	0,4	0,8	0,2	0,0	0,0	0,0	0,1	0,0	0,1	0,2	0,6
5th prosentil	0,1	0,0	0,3	0,2	0,3	0,1	0,0	0,0	0,0	0,0	0,0	0,1	0,1	0,3
min verdi	0,0	0,0	0,1	0,1	0,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,2
Sample størrelse	119	119	119	119	119	119	119	119	119	119	119	119	119	119
Faktisk størrelse	93	90	96	95	96	92	7	70	18	4	5	3	9	2

Bygningsdel	41	43	44	49	51	52	62	69	72	76	77
maks verdi	0,3	0,6	1,3	5,9	0,1	0,1	0,9	0,5	0,0	2,3	3,3
95. prosentil	0,3	0,6	1,1	5,7	0,1	0,1	0,8	0,5	0,0	2,1	3,3
75. prosentil	0,3	0,3	0,7	2,8	0,1	0,1	0,5	0,4	0,0	1,2	3,3
gjennomsnitt	0,2	0,2	0,5	1,9	0,1	0,1	0,4	0,3	0,0	0,8	3,3
median	0,2	0,1	0,2	1,7	0,1	0,1	0,2	0,2	0,0	0,0	3,3
25th prosentil	0,2	0,1	0,1	0,3	0,1	0,1	0,1	0,1	0,0	0,0	3,3
5th prosentil	0,1	0,0	0,0	0,0	0,1	0,1	0,1	0,1	0,0	0,0	3,3
min verdi	0,1	0,0	0,0	0,0	0,1	0,1	0,0	0,1	0,0	0,0	3,3
Sample størrelse	119	119	119	119	119	119	119	119	119	119	119
Faktisk størrelse	2	4	3	25	1	1	3	3	3	3	1

Resultater for statistisk analyse av livssyklusmoduler A1-A3 og B4 i referansefasen (kgCO$_2$e/m^2/år).

Bygningstype	Alle*	Boligbygg*	Kontorbygg*	Skolebygg*	Barnehage*	Rehabilitering
maks verdi	28,3	17,2	22,0	17,4	14,0	12,6
95. prosentil	18,6	15,4	21,3	14,4	11,9	10,3
75. prosentil	10,6	9,7	9,3	10,9	6,9	6,6
gjennomsnitt	8,5	8,1	8,8	7,6	6,8	5,7
median	6,5	8,0	7,0	6,1	5,9	5,4
25th prosentil	5,2	5,3	5,1	4,8	5,4	4,8
5th prosentil	3,0	4,9	4,5	2,9	4,3	2,0
min verdi	2,9	4,5	4,0	2,9	4,0	0,0
Sample størrelse	119	31	21	37	15	14
Faktisk størrelse	82	17	16	29	8	12

* Resultatene ekskluderer rehabiliteringsprosjekter.



NTNU
Kunnskap for en bedre verden