Master's thesis

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

Ingeborg Pahle Strømsnes

Investigating digital mapping to facilitate reuse in the Norwegian building stock.

Master's thesis in Sustainable Architecture
Supervisor: Gearóid Patrick Lydon
Co-supervisor: Kate Holm
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Kunnskap for en bedre verden

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AAR4993 - M.Sc. Thesis in Sustainable Architecture

Investigating digital mapping to facilitate reuse in the Norwegian building stock.

Author:
Ingeborg Pahle Strømsnes

Supervisor:
Gearóid Patrick Lydon

External Supervisor:
Kate Holm, Nordic Office of Architecture

June, 2024

Preface

This master's thesis has been developed at the Department of Architecture and Technology, Faculty of Architecture and Design, at the Norwegian University of Science and Technology (NTNU). The work was conducted in the spring of 2024 and is valued at 30 ECTS credits through the course AAR4993 - M.Sc. Thesis in Sustainable Architecture.

The thesis has been prepared by M.Sc. student Ingeborg Pahle Strømsnes with associate professor and deputy head of research at the Department of Architecture and Technology, Gearóid Patrick Lydon, serving as the supervisor at NTNU. The Nordic Office of Architecture and Norconsult have been engaged as collaborative partners led by Kate Holm. They have assisted with office space, site visits, engagement, and support throughout this semester. I have been allocated a workstation at their office, surrounded by knowledge, enthusiasm, and curiosity.

I would like to thank my advisor Gearóid for the weekly reviews, engagement, and support. His mentorship has been both a great inspiration and a source of motivation. I would also like to thank Kate Holm and all the employees at Nordic Office of Architecture for allowing me to work at their office and engage in many fascinating conversations and workshops. Thank you to all the interviewees and participants of the questionnaire for their valuable insights that have been important in this project. Furthermore, I wish to thank all participants of the interim and mid-term presentations at NTNU for their constructive feedback and insightful suggestions. Your contributions have been invaluable.

In closing, I would like to express my thanks to my family and friends for their support and motivation. A special thank you to Andreas, Maren, mom and dad for proofreading and support. Finally, I am thankful to my fellow students for the great years spent at NTNU.

Ingeborg P. Strømsnes

Ingeborg Pahle Strømsnes

Abstract

The construction industry faces a global challenge to significantly reduce greenhouse gas emissions. The majority of the buildings for the future are already constructed, and therefore, it is crucial to implement transformation more extensively than before. A successful transformation project requires precision and clarity in the mapping phase of materials, which is carried out to a very limited extent today. There are too few incentives for the reuse of materials in Norway's construction industry. In addition to emission challenges, the construction industry is far behind other industries regarding digital development. Therefore, this thesis will investigate methods used and technology developed within the early-phase stages of construction projects.

The purpose of the thesis is to combine challenges related to reuse and digitalisation to propose methods for facilitating reuse decisions more effectively. The thesis aims to understand the current mapping phase and how it interacts with new technologies. Building upon the new Norwegian regulation, "From July 1st, 2023, it became mandatory to perform a reuse mapping of building components that are to be removed", the thesis will investigate how to perform this mapping in the best possible way. The thesis explores standardisation, regulations, digitalisation, and circular economy to overview the industry's present and future opportunities comprehensively.

Through a mixed approach using both qualitative and quantitative methods, the main objective of the thesis is to gain insights from the industry to solve their issues regarding reuse and digitalisation. A construction project is complex and involves many stakeholders. Therefore, it has been important for the study to examine the entire value chain to get an overview of the initiative-takers and decision-makers in the industry. By employing a structured literature review, the findings served as a basis for further methods, including a questionnaire, interviews and case studies. The questionnaire results encompassed many disciplines within the industry, which was crucial for achieving a comprehensive overview of the industry's current challenges. Furthermore, the interviews were conducted with building owners, consultants, and industry professionals working on innovative solutions. These interviews were structured based on the questionnaire findings, allowing interviewees to elaborate on the identified issues.

The research findings underscore the importance of using Building Information Models (BIM) and comprehensive planning in the early stages to establish sustainable projects and tackle logistical challenges. Additionally, effective communication among all parties involved in a construction project is essential for enhancing decision-making processes. Other findings merge new technologies and digital models with physical material storage. Physical storage has rapidly evolved in Norway in recent years. The study proposes a hybrid solution for future reuse processes and underscores the concept of enhanced digital frameworks to facilitate improved logistics for physical storage. The thesis identifies primary challenges within the current reuse industry, questions government regulations, and proposes initiatives to increase reuse opportunities and standards. By exploring the combination of digital development and reuse potential, the dissertation aims to highlight the use of digital mapping with new technology to facilitate physical storage options.

Table of Contents

List of Figures

List of Tables

Definitions And Terms

For the purpose of clarification, central keywords and definitions are included.

Artificial Intelligence (AI).
A branch of computer science focused on machines performing tasks requiring human intelligence.

Building Information Modelling (BIM).
A digital representation of a building's physical and functional characteristics, used for design, construction, and facility management.

BREEAM.
'Building Research Establishment Environmental Assessment Methodology', a standard for rating systems of buildings and environmental assessment methods.

Building Technical Regulations (TEK).
Norwegian regulations governing technical requirements for construction works, including the mandatory reuse mapping of building components.

Circular Economy.
An economic system aimed at minimising waste and maximising resource use, contrasting with the traditional 'take, make, dispose' model.

Digital Roadmaps.
Strategic plans charting the route towards a digitised construction, architecture, and engineering industry, promoting cost-effectiveness and reduced emissions.

EU Taxonomy.
A classification system by the European Union to clarify environmentally sustainable investments, directing financial flows to sustainable projects.

FutureBuilt.
A Norwegian innovation program developing sustainable urban areas and buildings, exceeding international environmental goals and reducing emissions.

Greenwashing.
The act of making false or misleading statements about the environmental benefits of a product or practice.

Reuse Mapping.
A systematic review of building components to assess their suitability for reuse, promoting rehabilitation over demolition and reducing waste.

Sustainable Development Goals (SDGs)
A collection of 17 global goals set by the United Nations in 2015, addressing challenges related to poverty, inequality, climate change, and peace.

List of Abbreviations

AEC Architecture, Engineering, and Construction.

AI Artificial Intelligence.

BIM Building Information Modelling.

BIU BREEAM In-Use.

BREEAM Building Research Establishment Environmental Assessment Methodology.

CE Circular Economy.

CEN European Committee for Standardisation.

CLT Cross-Laminated Timber.

CO_2 Carbon Dioxide.

CSRD Corporate Sustainability Reporting Directive.

EE Embodied Emissions.

EEA European Economic Area.

EPD Environmental Product Declaration.

ESG Environmental, Social, and Governance.

EU European Union.

GHG Greenhouse Gases.

IoT Internet Of Things.

ISO International Organisation for Standardisation.

LCA Life Cycle Assessment.

NS Norwegian Standard.

RE Reversed Engineering.

SDG Sustainable Development Goals.

TEK The Norwegian Building Code.

1 Introduction

The introduction provides an overview of the thesis's background, outlining its goals and the methodology employed. It also covers the background and development of the research questions it seeks to answer. Lastly, it defines the thesis's scope and limitations, identifying potential opportunities for further exploration.

1.1 Background and Goals

The construction industry in Norway accounts for a significant share of national resources use, generating more than 25% of all waste in Norway (Thorp, 2024). A significant portion of today's waste can technically be reused if it is identified, documented, and made accessible to those who will use it (Grønn Byggallianse, 2024b). Reused resources have 90-99% lower emissions than newly produced ones (Grønn Byggallianse, 2024b). In light of an increased focus on resource use, as of 1st July 2023, there is a requirement for a reuse report in all Norwegian buildings to identify and document various materials with the potential for reuse (DIBK, 2017). The aim of this legal change is to gain a better overview of what is discarded and potentially reusable (Sirken, 2024).

In addition to an increasing focus on reuse, there is also a growing emphasis on digitalisation in the industry (Niemi, 2023). This approach will enable the use of new technology to improve productivity over the building life-cycle (Byggenæringens Landsforening, 2020). The domain covers many aspects of the construction industry, from process automation and digital twins of existing buildings to digital platforms for trade and collaboration (Standard Norge, 2024a). digitalisation in the construction industry can reduce greenhouse gas (GHG) emissions by 50%, ensure project completion 50% faster, and reduce costs by 33% (Niemi, 2023). Despite this advances, the Norwegian construction and civil engineering industry lags behind in digitalisation compared to other industries (Zahl et al., 2023).

Considering the new regulatory change, the thesis aims to explore and highlight the main challenges related to successful mapping and reuse. Digitalisation is an important tool for increasing sustainability and competitiveness in all industries. For that reason, the thesis will examine current and new technologies to find connections between reuse and digitalisation. The construction industry is fragmented and consists of many different actors. This characteristic can present a significant challenge to the digitalisation of the industry (Grønnestad, 2024). Therefore, the thesis explores many areas of the construction industry by covering all the different stages involved in a construction project to understand the intersection between new technologies and sustainability practices.

1.2 Thesis Statement and Research Questions

The thesis explores information flow across disciplines to understand how the industry is interconnected, and it aims to answer the following Research problem:

How can digital mapping improve material reuse in Norwegian construction projects?

The statement is anchored in three main research questions. The research questions seek to clarify the current situation and identify solutions for more effectively utilising the 20,000 buildings demolished each year in Norway (Widing, 2020). The questions were developed through conversations with industry professionals through a situational analysis conducted in January 2024. Here, architects, site owners, contractors, and digitalisation firms were asked to identify the most significant challenges in the construction industry. The discussions were structured through open-ended conversations, allowing topics to emerge naturally and guide the research direction. This approach provided a comprehensive foundation for exploring the complexities within the sector. The situational analysis concluded with three questions covering the topics of reuse, digitalisation and collaboration. The research questions are as follows (Table 1):

Table 1: Research Questions for the thesis.

No.	Research Question
1	How do stakeholder roles and interactions influence the effectiveness of material reuse strategies in the construction industry?
2	What early-phase mapping solutions have been developed to date, and how do these function in practice?
3	How can we facilitate increased reuse in the industry during the early stages of the project?

Questions 1 and 2 will establish the groundwork necessary for exploring question 3. Question 3 will also identify additional research opportunities that may extend the findings of this master's thesis. The questions will be answered using four methods: literature search, interviews, questionnaire and case studies. Chapter 4.1.2 will explain which methods will be employed for each aspect of the study.

1.3 Scope and Limitations

1.3.1 Scope

The thesis will cover three case projects and include in-depth discussions with various stakeholders in the construction industry. The case studies, interviews, and discussions are supported by insights obtained from a comprehensive literature and theory review. The main goal is to identify the primary challenges hindering efficient reuse practices and suggest new solutions to this issue.

1.3.2 Limitations

Databases

After testing different databases for the literature review, the queries were restricted to “Scopus” and “Web of Science” databases. These criteria were selected to guarantee that the volume of search results remained manageable and that the literature reviewed was highly pertinent to the thesis. This process is described in Chapter 3.1.1.

Literature Review

The literature addresses the international construction industry, which presents a potential weakness due to the varied regulations and practices across countries due to cultural and climate differences. Therefore, the theory chapter will primarily focus on Norwegian literature.

Interviews

Due to time constraints and keeping the scope manageable, the study excludes interviews with tenants or building materials manufacturers. This may affect the findings, but for the overarching aim of the thesis, it will yield more distinct insights.

Interview Questions

The thesis explicitly aims to explore cross-disciplinary areas within the industry. Therefore, employing a uniform interview guide for all participants would be impractical, given the considerable variation in their areas of expertise. This approach has resulted in an interview guide that includes common questions applicable to all interviewees, supplemented by personalised questions tailored to each participant’s specific roles and expertise. This design is categorised as semi-structured.

Case Studies

The study includes case studies of medium-sized projects focusing on reuse. The size was selected to provide a comprehensive view and facilitate discussions with a broad range of participants. Larger-scale projects may have influenced the results, as they specifically affect parameters such as cost, logistics, and the number of stakeholders involved.

1.4 Structure of the Thesis

The structure and organisation of the thesis are based on the IMRaD model (NTNU, n.d.). The IMRaD model comprises the areas *Introduction*, *Material/method*, *Results* and *Discussion*. The original model has been modified to cover all desired areas for the thesis. Additionally, a literature review has been included as a separate chapter, as it encompasses a wide area. Table 2 presents the structure of this thesis and provides a brief summary of the contents of each chapter. The table is divided into "Introduction", "Main Section", and "Conclusion".

Table 2: Structure of the thesis.

Structure	**Chapter**	**Description**
Introduction	Introduction	Presents the background of the thesis, the methodology used and the research questions that the thesis aims to address. Describes scope, limitations and opportunities.
Main Section	Theoretical Background	Presents the context, guides the research and provides a foundation for further work. This chapter facilitated discussion and the conclusion in the following chapters.
	Literature Review	A systematic literature review evaluated existing field literature, offering a solid basis for further empirical methods like interviews and case studies in subsequent chapters.
	Methodology	Explains and describes the method used to acquire knowledge and answer the research question of the thesis. The methodology includes case studies and describes the sites and how various reuse decisions have influenced the projects.
	Results	Presents the results found through literature search, semi-structured interviews, interviews, and case studies.
	Discussion	Discussion of findings from the results chapter in relation to the thesis's three main research questions.
Conclusion	Conclusion	Summarise the main findings to answer the research questions and suggest areas for further investigation of relevance.

2 Theoretical Background

This chapter provides information on the theory that serves as the foundation of the report and aims to provide a clear understanding of its key principles. It includes discussions on the construction industry, regulations, digitalisation, and reuse.

2.1 Greenhouse Gas Emissions

Responsible for around 37% of all global emissions, the construction industry is the largest emitter of greenhouse gases (GHG) (UNEP, 2023). These emissions consist of direct and indirect emissions. The direct emissions consists of raw materials, energy use, solid waste, land use and water use (Ibn-Mohammed et al., 2013). The indirect emissions, also known as embodied emissions (EE), consist of extraction, production and transportation of materials. It also describes reuse, disposal of materials, deconstruction and end-of-life (Resch, 2021). Figure 1 illustrates the construction sector's share of Norway's greenhouse gas emissions.

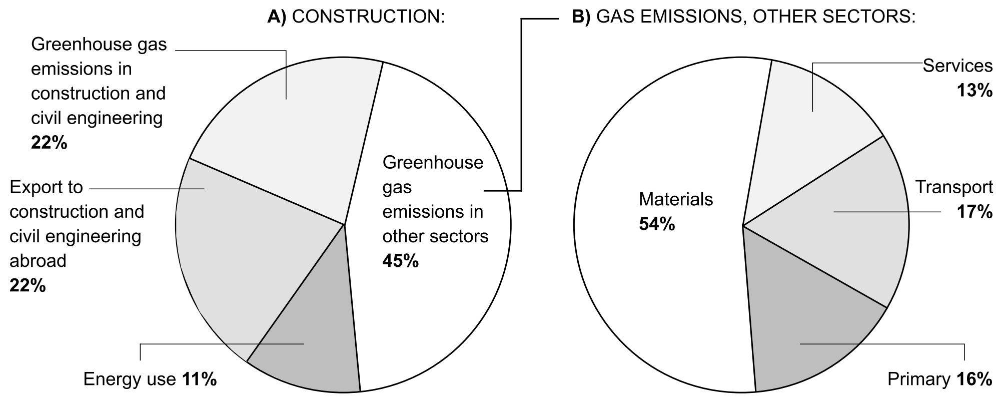

Figure 1: The construction sector's share of Norway's GHG emissions (Byggenæringens Landsforening, 2017a). Chart A describes the distribution of the 15.3% of GHG emissions attributed to Norway's construction sector in 2017. The remaining 45% in chart A, is illustrated in chart B. There, 54% are from the production of building materials. Other contributions are distributed among services, transport, and primary industries.

Emission Categories

Greenhouse gas emissions (GHG) have been categorised into three distinct scopes: Scope 1, Scope 2, and Scope 3 (Greenhouse Gas Protocol, 2023). These categories aim to differentiate between direct and indirect sources of emissions, enhance transparency, and offer applicability for various climate policies and business objectives. The three scopes include:

- **Scope 1 Emissions**: all fuels burnt directly from sources owned or controlled by a company.
- **Scope 2 Emissions**: all emissions burnt indirectly from purchased electricity, steam, heat and cooling.
- **Scope 3 Emissions**: indirect emissions, meaning emissions not from the company itself but from all emissions in the value chain.

Energy efficiency has developed a lot in the last few years, and the operational emissions, such as emissions from heating, cooling, and lighting in this area have heavily increased (Ibn-Mohammed et al., 2013). The indirect emissions in Scope 3 related to material use, including embodied emissions (EE), are increasingly important in energy-efficient modern buildings. It is essential to develop methods that enable the assessment of climate change impacts resulting from material design during the initial stages of a project (Resch, 2021).

2.1.1 Political Objectives

"Norways Climate Action Plan" was presented to the Norwegian parliamen) in January 2021 under the administration of Erna Solberg's government. The document outlines the government's strategy for reducing Norwegian emissions by 2030. The current target aims for a reduction of greenhouse gas emissions by at least 50% and up to 55% from 1990 levels by 2030. This enhanced target, set in 2020, is an increase from the previous goal of 40%. The overarching aim is to "Cut emissions, not development" (Klima- og miljødepartementet, 2021). Figure 2 is showing the reference value in 1990 and the new goals by 2030 and 2050 from the action plan. The goals are part of the Paris Agreement, a legally binding international treaty involving the majority of United Nations member states (Bjørnnes and Kjølstad, 2021). The primary objective of the agreement is to limit global temperature increases to well below 2°C.

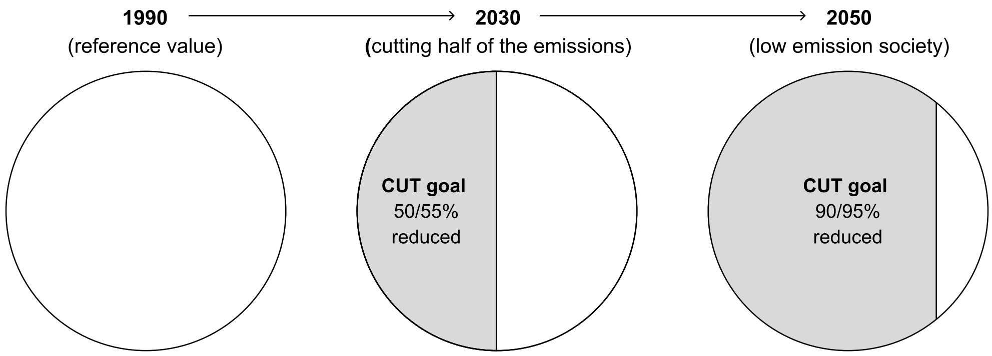

Figure 2: Norways Climate action plan, including reference value from 1990 and the newgoals 2030 and 2050 (Klima- og miljødepartementet, 2021). By 2030 Norway will reduce emissions by 50-55% and by 2050 cut by 90-95%.

2.2 Overview of the Norwegian Industry

In Norway, 20,000 buildings are demolished each year (Widing, 2020). Some are dismantled before their normative lifespan, despite having fully usable building components with a significant remaining useful life (Nitter, 2023). Effective from July 1, 2022, with a one-year grace period, a mandatory requirement was introduced through the Building Technical Regulations (TEK), § 9-7 (DIBK, 2017). This regulation mandates reuse mapping for actions involving residential blocks or commercial buildings larger than 100 square meters or producing more than 10 tons of waste. TEK is directed towards parties responsible for the construction project and the enterprises accountable in a building case (Kilvær and Granlund, 2023).

A reuse mapping is a systematic review of building components within a structure or area to assess their suitability for reuse (Nitter, 2023). The objective of reuse mapping is to highlight the potential for rehabilitation over demolition, and a systematic mapping strategy can be seen in Figure 3. Research conducted by SINTEF (one of Europe's largest independent research organisations) indicates significant greenhouse gas reductions through the refurbishment of existing buildings (Nitter, 2023). The study of Norwegian renovations reveals that refurbishment results in only a third of the emissions compared to new construction (Fufa et al., 2020). A significant part of today's material waste can be reused if it is mapped, documented and arranged for those who will use it (Grønn Byggallianse, 2023b).

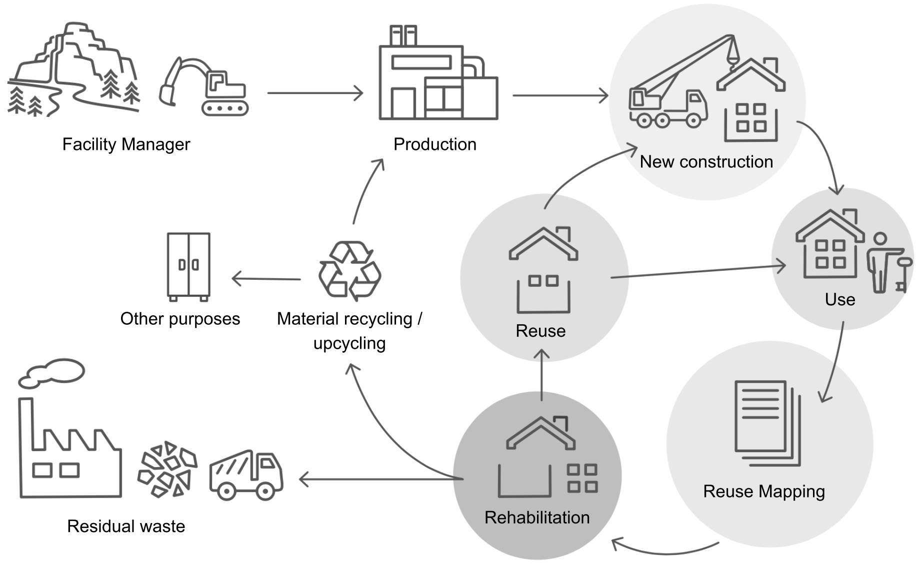

Figure 3: Lifecycle of a building and systematic reuse mapping (Grønn Byggallianse, 2023b).

Waste from Construction

Construction materials account for 30 percent of all waste in Norway (Direktoratet for byggkvalitet, DiBK, 2022). The amount of waste increases each year, and in 2022, it accounted for over 2 million tons as seen in Table 3. Choosing rehabilitation over demolition offers significant environmental benefits, potentially reducing annual CO_2 emissions by an estimated 2.4 million tons, according to an analysis conducted by Asplan Viak (2023).

Table 3: Generated waste amounts from new construction, renovation, and demolition in Norway in 2022 (Statistisk Sentralbyrå, 2022).

Type	**Tons**	**Percentage**
New Construction	641 535	30,4
Renovation	566 200	26,8
Demolition	903 385	42,8
Total	**2 111 120**	**100,0**

Primary Contributors

The EU's Waste Directive, which Norway has joined through the EEA Agreement, set a goal that 70 percent of waste from both construction and demolition activities should be recycled by 2020 (Statistisk Sentralbyrå, 2018). This goal was not achieved, and waste in the industry is still a significant problem, as favourable recycling methods have not been adequately facilitated. In Figure 4 from 2016, it is evident that bricks, concrete, and other heavy materials are the primary contributors to waste generation. Their significant weight and recycling challenges make them the major source of emissions (Statistisk Sentralbyrå, 2018).

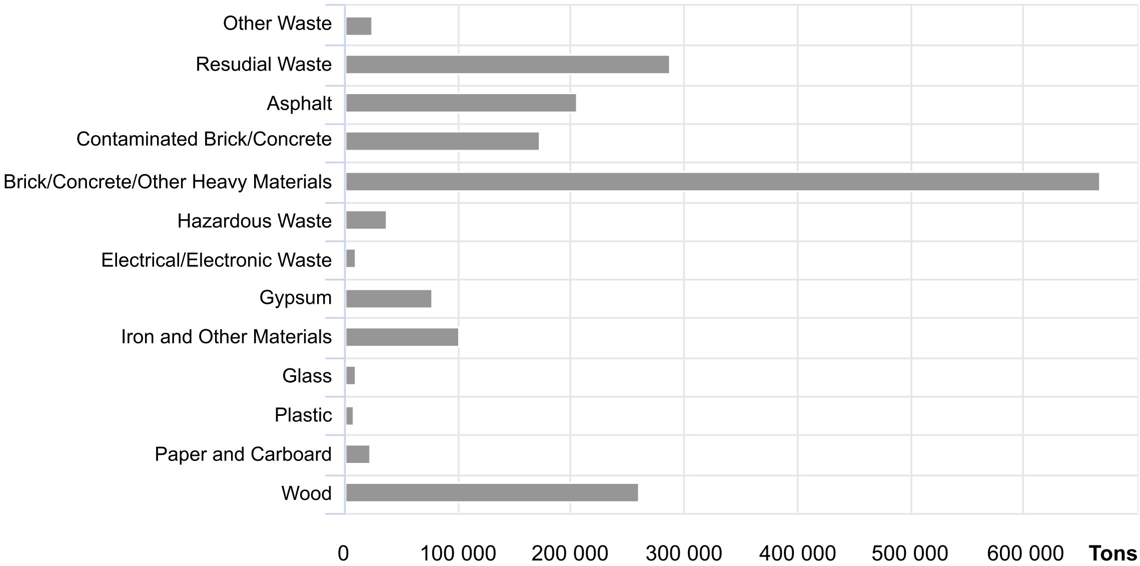

Figure 4: Generated amounts of waste from new construction, rehabilitation, and demolition in Norway, 2016 (Statistisk Sentralbyrå, 2018).

Concrete and Bricks

The challenge with concrete is the substantial energy required to produce cement and crush stone into aggregate. When a concrete element is crushed and used as filling material, little of this "invested" energy is utilised. For brick, the strong cement mortar used today complicates deconstruction, as it tends to crush rather than being disassembled logically. This limits its use to filling material, and the energy expended in the heating process is consequently lost (Nordby and Wærner, 2017). Lime mortar is considered an alternative approach, as its slightly weaker binding properties allow for disassembly without crushing the bricks (Forsvarsbygg, 2016).

Waste Hierarchy

The waste hierarchy pyramid (Figure 5) is a concept in Norwegian waste policy and the EU's Waste Framework Directive. The pyramid describes the priorities in waste policy, dictating that waste should be managed as close to the top of the pyramid as possible (AvfallNorge, 2022). The objective of the pyramid is to promote a perspective that sees waste not as a problem, but as a potential resource for creating new processes using old materials (Nordby and Wærner, 2017).

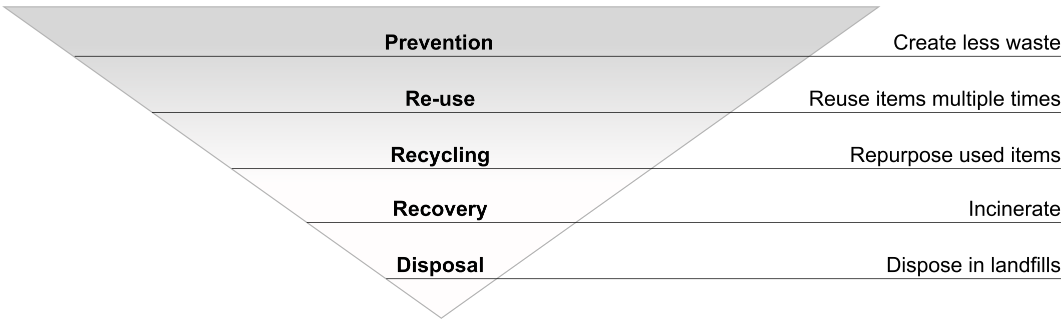

Figure 5: The Waste Hierarchy Pyramid adapted from AvfallNorge (2022).

Waste amount per square meter and the lifespan of buildings are the two controlling factors for waste generation. The Chapter 2.3 examines the new TEK17 requirements for sorting at construction sites. However, the authorities have not yet set a maximum limit for the amount of building waste that is acceptable. Currently, environmental projects aim for a maximum of 25 kg/m^2, approximately half of the typical current figures of 40-60 kg of waste per square meter (Nordby and Wærner, 2017).

2.3 Current Regulations and Recommendations

United Nations: Sustainable Development Goals

To address global greenhouse gas emissions, the United Nations has developed 17 Sustainable Development Goals (SDG) and 169 sub-goals (United Nations, 2023). These are designed to act as guiding parameters, facilitating the adoption of sustainable choices. The goals relevant to a more sustainable construction industry are highlighted in Figure 6. The others are part of the SDG but are not directly relevant to this thesis. However, given the complexity of sustainability, the greyed-out goals can still be influenced by the aspects being focused on in the study.

Figure 6: Relevant UN Sustainable Development Goals (SDG) for this thesis adapted from United Nations (2023).

BREEAM

BREEAM is the world's oldest (established in 1990) and Europe's leading environmental certification tool for buildings. BREEAM-NOR is the Norwegian adaptation of BREEAM and the construction industry's tool for measuring environmental performance, developed by the Norwegian Green Building Council (Norsk Byggtjeneste, 2024). BREEAM consists of two different categories for certification:

- **BREEAM in-use**
  BREEAM In-Use (BIU) is a distinct standard for existing buildings. It serves as a tool to measure, improve, and document environmental performance and health-promoting qualities in existing structures. The manual comprises two certification parts: Part 1 (Property) and Part 2 (Management) (Grønn Byggallianse, 2024a).

- **BREEAM-NOR**
  A BREEAM-NOR certificate is issued at five levels: Pass, Good, Very Good, Excellent, and Outstanding, as seen in Figure 7. The certification is based on documented environmental performance in the categories management, health and indoor environment, energy, transportation, water, materials, waste, land use and ecology, and pollution (Norsk Byggtjeneste, 2024).

BIU and BREEAM-NOR are two distinct certification systems where BREEAM-NOR focuses on the construction process, while BIU concentrates on a building's environmental qualities during the operational phase. In Norway today, there are just over 300 registered BREEAM projects (Grønn Byggallianse, 2024a).

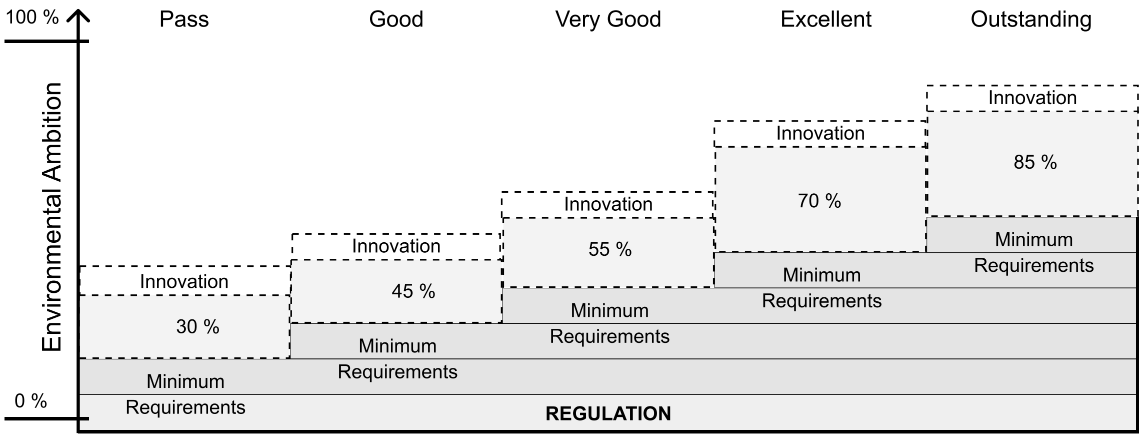

Figure 7: BREEAM certification levels (Grønn Byggallianse, 2024a).

EU Taxonomy
The EU Taxonomy is central to the European Commission's action plan for sustainable finance. This classification system includes initiatives to improve the decision-making basis for investors and to enhance the market for sustainable investments (Grønn Byggallianse, 2024c). This impacts the construction sector as it leads to better conditions for sustainable buildings, and in the future, absolute requirements will be set for financing and insurance. Additionally, the EU states that the criteria from the taxonomy will form the basis for the allocation of research funds from programs like Horizon Europe and Invest EU. This serves as an incentive for projects to comply with the criteria to qualify for funding.

FutureBuilt
FutureBuilt is a Norwegian innovation program with a vision to demonstrate that it is possible to develop sustainable and attractive zero-emission cities. Its goal is to realise 100 exemplary projects, including urban areas and individual buildings, that exceed the UN's sustainability goals

and the Paris Agreement targets, always reducing greenhouse gas emissions by at least 50 percent compared to standard practices (FutureBuilt, 2016b). The exemplary projects are required to meet a set of quality criteria closely aligned with BREEAM-NOR standards (FutureBuilt, 2016a).

TEK17

The Norwegian Building Technical Regulations (TEK) is a regulation that sets out requirements for the design and execution of measures under the Planning and Building Act to ensure considerations of energy, environment, health, and safety (Lovdata, 2023). The new building technical regulations came into effect on July 1, 2017, and is therefore called "17" (DIBK, 2017). The relevant regulations for reuse and sorting are as follows:

> ***§ 9-1. General requirements for the external environment***
> *"Buildings should be designed, constructed, operated, and demolished in a manner that minimises the strain on natural resources and the external environment. The handling of building waste should be managed accordingly." (DIBK, 2017)*

> ***§ 9-5. Building Waste and Reuse***
> *"Products suitable for reuse and material recycling should be chosen. Buildings should be designed and constructed to facilitate future dismantling when it can be carried out within a practical and economically justifiable framework." (DIBK, 2017)*

> ***§ 9-7. Mapping of hazardous waste, building fractions that must be removed, and materials suitable for reuse. Requirements for reporting.***
> *"(3) ...A dedicated report must be created for the reuse mapping." (DIBK, 2017)*

> ***§ 9-8. Waste Sorting***
> *"A minimum of 70 percent by weight of the waste must be sorted into clean types of waste (...) all waste must be delivered to approved waste facilities, for reuse, or directly for recycling." (DIBK, 2017)*

> ***§ 17-1. Greenhouse Gas Accounting from Materials***
> *"For the construction and major renovation of apartment- and commercial buildings, a greenhouse gas account must be prepared." (DIBK, 2017)*

Regulations are continually evolving, and on July 1, 2022, amendments were made to the energy, climate, and environmental requirements in the Building Technical Regulations, along with associated changes in the Building Application Regulations (DIBK, 2022). The amendment was as follows:

> *"From July 1, 2022, new buildings must be constructed in a way that allows for future dismantling, and materials should be mapped for reuse in major works on existing buildings. The requirement for waste sorting at construction sites increases from 60 to 70 percent. Additionally, a requirement for a greenhouse gas account for apartment buildings and commercial buildings has been introduced."*

The requirement for reuse mapping necessitates the generation of a substantial volume of data from the mapping process, which must also demonstrate the degree of reusability. The amendments have not specified detailed requirements or guidelines for the preparation of this report. Efforts are currently underway to develop a proposal for a common manual to systematise this mapping process (Trøndelag fylkeskommune, 2023).

ISO, CEN and NS Standards

In Europe, the world and Norway, there are different organisations concerned with standardisation. The international organisation is called the International Organisation for Standardisation (ISO), and the European organisation is called the European Committee for Standardisation (CEN) (Youd, 1995). In Norway, we have "Norsk Standard" (NS), which is responsible for standardisation tasks in all areas except electrical and telecommunications standardisation (Standard Norge, 2024b). Standard Norge has the exclusive right to establish and publish Norwegian standards and is the Norwegian member of CEN and ISO. Figure 8 shows an overview of the organisational chart internationally, in Europe and in Norway (Standard Norge, 2024b).

Figure 8: Standardisation chart showing the International Organisation for Standardisation (ISO), the European Committee for Standardisation (CEN) and Norsk Standard (NS).

The figure emphasises how these different elements influence each other, highlighting that the Norwegian NS is influenced by both European and international organisations. As the standards are developed in later years, there is an increased emphasis on sustainability and the principles of circular economy. For example, the new standards "NS-EN 17680:2023" (Arkitektforbundet, 2024) and "ISO 59004" (ISO, 2024) developed in 2023 and 2024, place a greater emphasis on sustainability and the circular economy (CE) compared to previous standards. These changes highlight the ongoing effort to promote environmentally friendly practices through standardisation.

2.4 Stakeholders

A construction project is complex, involving numerous disciplines and roles. Each project is unique in size, contract, terms and objectives. The organisational chart presented in Figure 9 suggests a typical layout for a large-scale construction project but is not representative of every project. The overview was developed in collaboration with interview subjects and industry partners. The different stakeholders shown in Figure 9 are explained underneath the Figure.

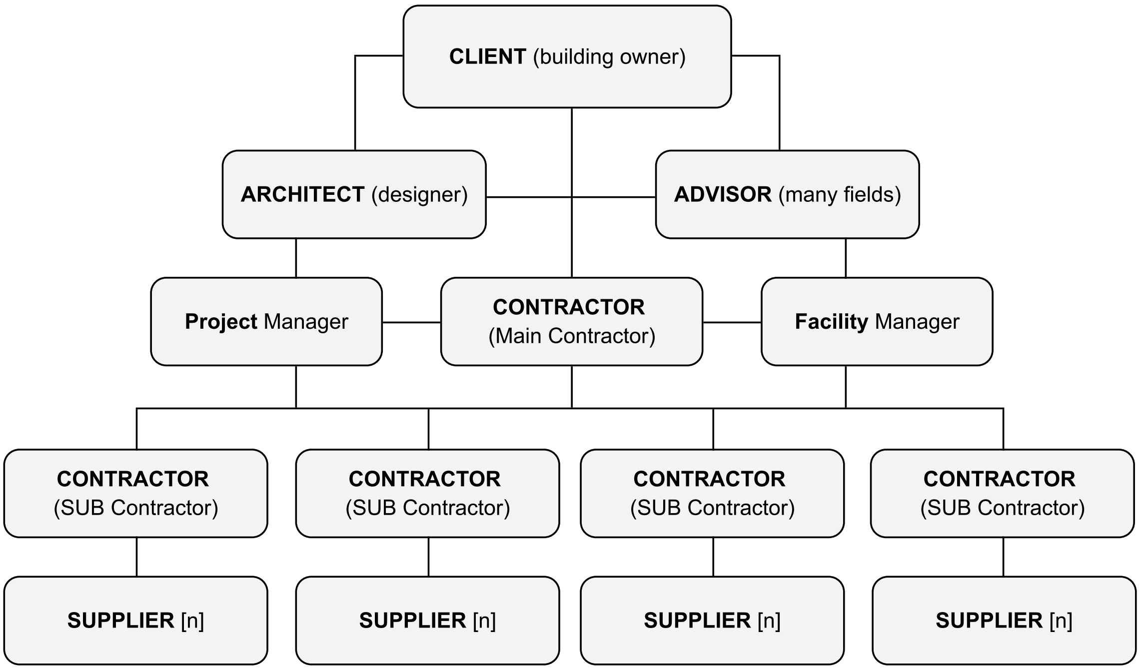

Figure 9: Organisational Chart in a general and typical Norwegian construction project.

Client

Any physical or legal entity that commissions a construction or civil engineering project (Arbeidstilsynet, 2020). The client initiates and conceptualises the project, ensuring its feasibility. Responsible for setting the budget and securing financing, the clients are usually the decisive link in decision-making processes. This structure makes clients a critical element for the thesis, as it necessitates analysing the client's transformation, reuse, and laser scanning initiatives.

Architect

The architect collaborates extensively with construction managers, engineers, and contractors. The architect is primarily responsible for constructing the project's design and layout. In recent times, the role of the architect in the circular economy has been discussed, and many argue that the architect's role will undergo changes and the new architect is seen as "the creative seeker who creates with what is already available" (Hogfeldt-Eskevik, 2023).

Advisor

The advisor calculates, plans, drafts, and supervises the execution of specific work areas in a building project. The project's various advisors are experts in different fields. In the execution phase, the advisors typically have the responsibility to ensure that the work aligns with the project planning documents within their area of expertise (DFØ, 2023).

Project Manager
The project manager reports progress and status to the project owner/client (Wålberg, 2022). The role of a project manager significantly changes with the size of the project. In smaller projects, the project manager often needs to perform technical work in addition to project management tasks, whereas in larger projects, all technical work is delegated.

Facility Manager
While the project manager focuses on the planning and completion of a construction project, the facility manager helps ensure the functionality, comfort and equipment both during the construction phase as well as when finished. They work closely with the general contractor and project superintendent during construction, conducting regular site inspections and quality checks (Engstrom, 2021).

Main Contractor
In addition to performing construction and civil engineering work, the main contractor is responsible for the project design according to the client's wishes (Granlund, 2022). They are responsible for day-to-day site management and coordinating labour, materials, and services. This role includes subcontractor management, ensuring that specialised parts of the project are executed according to plan. Financial oversight is a key responsibility, encompassing budget management and timely payments to parties involved.

Sub Contractor
The subcontractor operates under the guidance and supervision of the main contractor, who remains ultimately responsible for the project's overall completion. They specialise in particular areas, such as electrical, plumbing, or roofing, bringing expertise that the main contractor may not possess.

Supplier
A supplier provides materials, equipment, or specific services necessary for a construction project. They coordinate closely with contractors to meet specific requirements and delivery schedules.

2.4.1 Contracts and Impact

Opportunity for Impact
As seen in Figure 10, according to Hansen (2019), the potential for influence diminishes, and the consequences escalate as a project progresses. If a sudden change is desired, deliveries may be bound by contracts and possibly already executed. The figure illustrates how the project's influence graph and knowledge about the project graph develop along approximately similar curves in opposite directions. The curves intersect relatively early in the design phase, indicating that the project is far from completion when this intersection occurs. In addition to this, the cost curve increases at a steady pace towards the production phase, where it then sharply rises. It is the NS 8407 standard for turnkey contracts, typically accompanied by NS 8415 and NS 8417 standards for executing parties that establish guidelines for managing and processing deadlines and changes (Standard Norge, 2011).

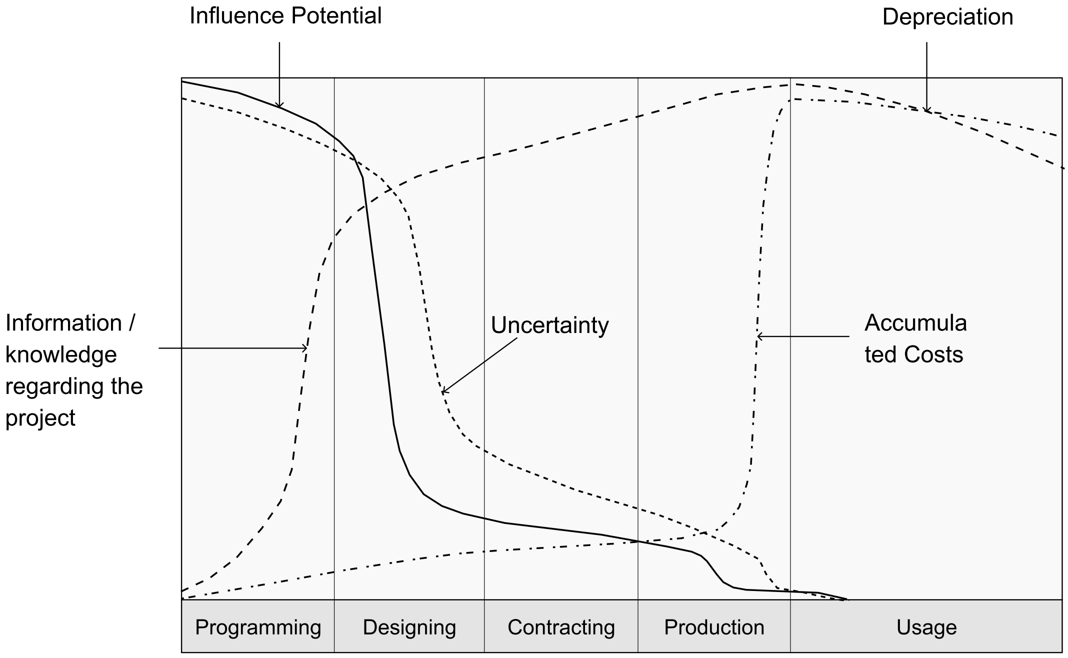

Figure 10: Oppurtunity for impact (Hansen, 2019).

Contracts

Contract models range from execution contracts, where the client delivers design and the contractor manages construction, to turnkey contracts, with the contractor overseeing both design and construction (Standard Norge, 2011). Turnkey contracts are prevalent in construction, where a single entity handles design and execution. This variation influences the responsibilities of key stakeholders, requiring them to adapt their roles and coordination efforts according to the contract's structure. In Norway, it is mandatory for public projects to be conducted using government acquisition. This refers to the process by which governmental, regional, and municipal authorities purchase construction works from private suppliers (Regjeringen, n.d). Consequently, both private and public project owners (Clients) often engage the same firms for their projects.

2.5 Circular Economy

It is crucial for the environment, climate, and nature that we use fewer resources in the future than we do today. Transitioning to a Circular Economy (CE) is a vital prerequisite for achieving this (Miljødirektoratet, 2021). Until now, the population has followed a linear economy model, extracting, producing, and using products that are either incinerated or disposed of at the end of their lifespan. Drawing on the principle that "everything is an input to everything else" (Pearce and Turner, 1989), the term circular economy was first formally used in Pearce and Turners model taking a critical look at the traditional linear economic system. The model incorporated three economic functions of the environment: resource supplier, waste assimilator and source of utility. The concept of circularity has been further applied in various industries and is highly relevant in the construction sector, as seen in Figure 11.

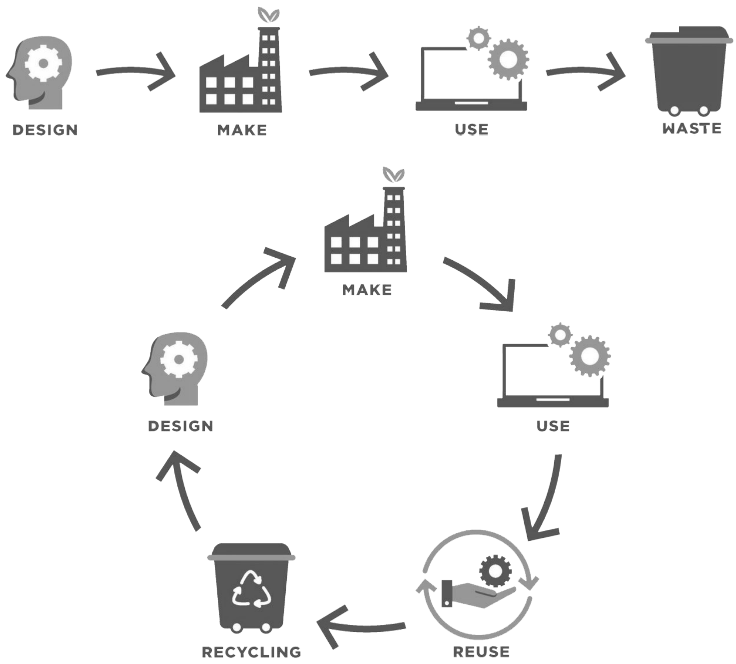

Figure 11: Illustrations representing the concept of Linear Economy (top) and Circular Economy (bottom) (Exenia, n.d.).

The concept of the CE is continually evolving, leading to the absence of a universally accepted definition. Despite this, the Norwegian Action Plan for Construction and Demolition Waste (Nasjonal handlingsplan for bygg- og anleggsavfall) has defined the term as follows (Landet et al., 2021):

"A circular economy is based on reuse, repair, renovation/improvement, and material recycling in a cycle where the fewest possible resources are lost."

This definition shall constitute the foundational basis for the concept of a CE within the scope of this thesis. The action plan aims to establish national objectives and aspirations for the construction, civil engineering, and recycling industries regarding waste reduction, proper sorting, responsible management, and material recycling of construction and demolition waste (Landet et al., 2021).

Norwegian Action Plan

In 2024, the government formulated an action plan detailing strategies to transition from a linear to a circular economy (Klima- og miljødepartementet, 2024). In this action plan, the government presents clear and targeted measures to facilitate the transition as quickly as possible in a manner that reduces waste and promotes new value creation.

"The government's vision is for Norway to be a pioneering country in the development of a green, circular economy that reduces the overall environmental and climate burden and creates new jobs throughout the country." - Klima- og miljødepartementet, 2024

According to the government, a new law on sustainable products and value chains will be presented to the Parliament later in 2024. The law will impose new sustainability requirements on selected value chains, from vehicles to batteries and from plastics to textiles. These requirements will encompass sustainability throughout the entire life-cycle of the products. In addition, the regulations for public procurement have been amended to include mandatory climate and environmental requirements for all public procurement as of today (Landet et al., 2021).

2.6 Digital Development

2.6.1 Digital Development and Artificial Intelligence

Artificial Intelligence (AI), a branch of computer science, originated in the 1950s, traces its foundational ideas to Alan Turing's seminal 1950 article "Computing Machinery and Intelligence". Among the diverse subfields of AI are Robotics, Machine Learning, Computer Vision, Automated Planning and Optimisation (Yussuf and Asfour, 2024). AI is typically defined as "the ability of machines to perform tasks that typically require human intelligence" (Minsky, 1961). Over the past decade, advancements in AI have transformed various sectors of society and blurred the lines between reality and artificial constructs. This evolution has been especially pronounced with the advent of generative AI models such as digital media and "ChatGPT" produced by Open AI (Califano and Spence, 2024). According to Yussuf and Asfour (2024), the integration of AI and digitalisation into construction practices can improve sustainability and increase energy efficiency in buildings. The increasing importance of AI and digitalisation in construction highlights their crucial role in shaping the industry's future and will be explained in the next Chapter.

2.6.2 Digital Development in Construction

A recent McKinsey Global Institute analysis of 22 major industries showed that construction was second to last for overall digitalisation rates, ranking above only hunting and agriculture (Fuchs et al., 2017). Digitalisation plays a significant role in promoting the circular economy (European Commission, 2020). This innovation aligns with SDG 9 (Industry, Innovation, and Infrastructure), 11 (Sustainable Cities and Communities), and 7 (Affordable and Clean Energy). The goals can be seen in Chapter 2.3.

Digitalisation Rates
The construction industry is fragmented, with organisations often differing significantly in size, capabilities and management approaches. With thousands of tools on the market, the McKinsey Global Institute analysis findings showed that many companies struggle to identify a portfolio of digital solutions that truly addresses their biggest challenges (Fuchs et al., 2017). The analysis also suggested that when applied comprehensively and efficiently, existing digital technologies can reduce overall project costs by as much as 45 percent and it states that "Construction has the benefit of learning from many other industries that have undergone significant digital transformations over the past five years" (Fuchs et al., 2017). The rapid progress of AI and its widespread applications have underscored the importance of efficient data translation, which continues to be a challenge in AI research (Yussuf and Asfour, 2024).

Building Information Modelling

A significant digital development within the industry is the adoption of Building Information Modeling (BIM). BIM entails a digital representation of a building's physical and functional characteristics. The concept involves 3D modeling concepts, alongside information database technology and interoperable software (Nordic BIM group, 2024). This integrated system operates within a desktop computer environment, allowing architects, engineers, and contractors to design facilities and simulate construction processes (Kubba, 2012). A BIM serves as a shared knowledge resource for information about a facility, as seen in Figure 12, providing a reliable basis for decision-making throughout its life-cycle, from initial conception to demolition. BIM is used by all stakeholders in a project, with each discipline having its own model (Nordic BIM group, 2024).

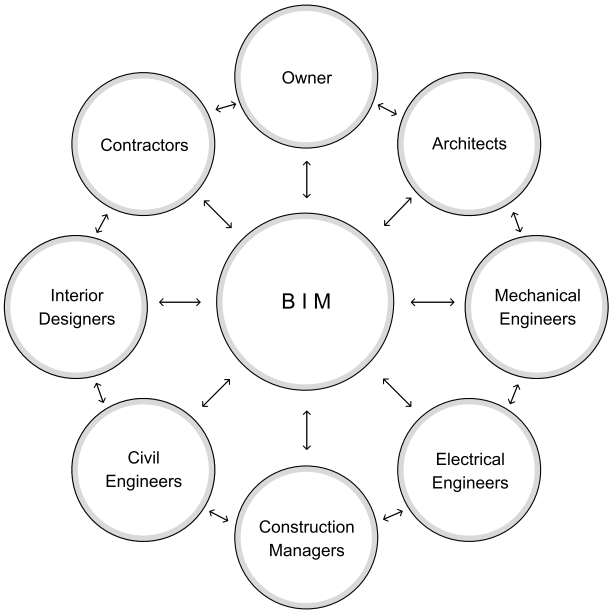

Figure 12: Relationship between BIM and stakeholders (Kubba, 2012).

Scan-to-BIM & Point-Clouds

Furthermore, the concept "Scan-to-BIM" has emerged. Creating as-is BIMs from laser scan data, also known as scan-to-BIM (Figure 13), involves converting detailed laser scan data into Building Information Models. A laser scanner accurately captures 3D data as point clouds from a building structure. Using 3D BIM software, this data is then transformed into as-built models, which faithfully represent the actual design within its real-world context (QeCAD, 2024).

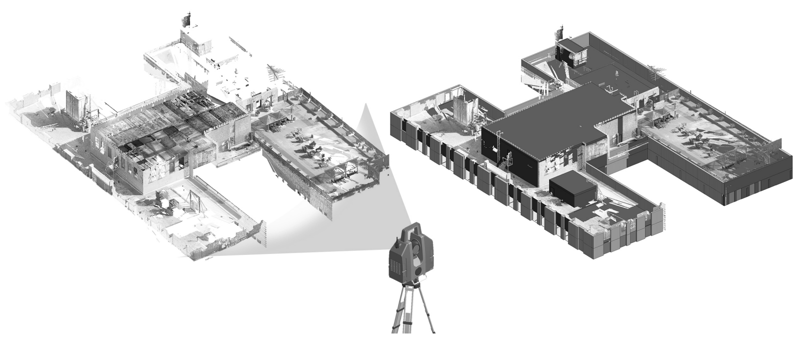

Figure 13: Input and Output using Scan-To-BIM (QeCAD, 2024).

Today, the term “scan” refers to techniques and methods capable of generating point clouds. Prior to the industry’s adoption of point clouds, the term “scan” referred to the process of obtaining spatial data, which from the earliest applications in the Architecture, Engineering and Construction (AEC) sector, involved the use of laser scanning (Pepe et al., 2024). In current industry practice, laser scan data is typically entered manually into BIM authoring tools, and BIM models are then generated using this reference data (Wang, Guo et al., 2019). A 3D point cloud is a collection of points in 3D space, defined by X, Y, and Z coordinates, representing an object’s surface. This data can be gathered from laser scans, images, and videos using various technologies (Wang and Kim, 2019). An example of a collection of coordinates on site can be seen in Figure 14.

Figure 14: Laser scanning with point-cloud technology. The scanner (right side of the image) is moved around the project and collects coordinates (Meridian Surveying Engineering, Inc., n.d.).

Scan-to-BIM Development

Scan-to-BIM is continuously evolving, with the latest advancement involving the integration of laser scanning with 360°cameras. This innovation allows for multiple visualisations of a space from the captured images. Combining laser scanning and camera imagery makes it possible to navigate digitally through the space via the digital twin (GD, n.d). Figure 15 illustrates an example of the 360°camera technology (left) and the digital integration (right).

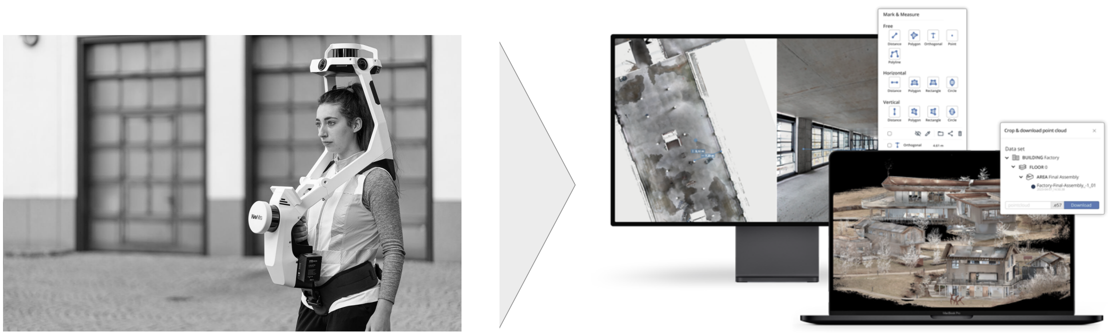

Figure 15: New technology within laser scanning. The left picture illustrates an example of the 360°camera technology, and the digital integration is illustrated in the right picture (GD, n.d).

Digital Roadmaps

Since 2017, the Building Industry Association, Norway's foremost organisation representing companies and employers in the construction sector, has released two digital roadmaps. These roadmaps are strategically designed to chart the most efficient route towards a comprehensively digitised construction, architecture, and engineering industry. The roadmaps specifically target decision-makers within those segments of the industry considered to have the greatest influence on digitalisation: developers/building owners, material owners, public authorities, and the industry's trade organisations. The roadmap suggests measures in the categories of enablers, products, prerequisites, goals, and vision. Special emphasis is placed on the digital construction site and digital twin. The steps are illustrated in Figure 16.

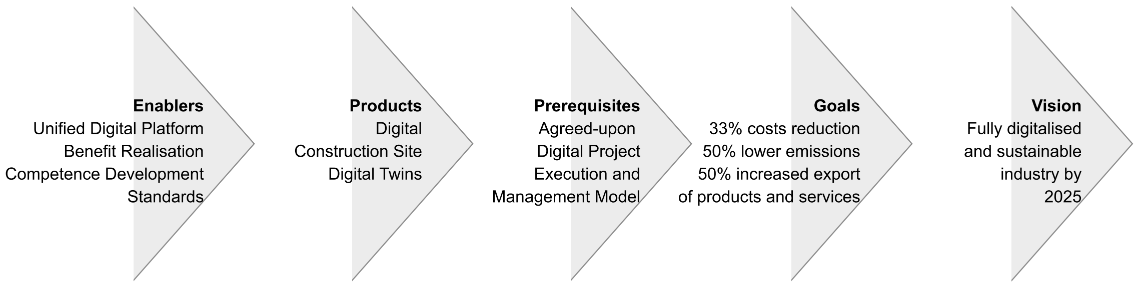

Figure 16: Main elements of the digital Roadmap by Byggenæringens Landsforening (2017b).

The roadmap is defined by the following vision (Byggenæringens Landsforening, 2017b):

"Through fully digital planning, execution, and operation with digitally supported work processes, the aim is to achieve outcomes in the form of more cost-effective and improved buildings, reduced greenhouse gas emissions, more efficient use of resources, and increased export of products and services."

In 2020, Digital Roadmap 2.0 was produced as a supplement to Digital Roadmap 1.0, aimed at anchoring digitalisation strategies among leaders in relevant businesses. The objective is to enable the industry to understand the reasons and methods for proceeding with the digitalisation process (Byggenæringens Landsforening, 2020). The roadmap provides advice on digitalisation, industry trends, industry examples, and opportunities around future digital technology. Particularly noteworthy, it highlights the use of AI, algorithms, and sensor technology as effective methods for future digitalisation.

Specific findings from the roadmap for this thesis were (Byggenæringens Landsforening, 2020):

- Understand the principles of artificial intelligence for further efficiency
- Document properties via Environmental Product Declarations
- Establish slim-BIM for continuous enrichment of digital knowledge
- Demand machine-readable product information from your suppliers
- Collaborate on BIM competence training at all levels

- Share findings with the industry as a whole
- Seek collaboration with others in the value chain
- Focus on building company-wide competence and be open to change
- Ensure all environmental properties are made machine-readable

In a survey conducted by Niemi (2023), 500 individuals working in the construction and civil engineering industry in Norway were asked about various topics, including digitalisation and sustainability. According to the report, the largest barrier to digitalisation is limited knowledge regarding the topic. Several respondents believe that digital solutions are the key to a construction and civil engineering industry that is more productive, environmentally friendly, and profitable (Niemi, 2023).

The DIPLOM Project
In 2023, an innovation partnership was established, led by Trøndelag County Council in collaboration with the Directorate for Public Management and Budget, the Supplier Development Programme, and Innovation Norway. Partner organisations in the initiative include Trondheim Municipality, OsloBygg KF, the Norwegian Defence Estates Agency, the Norwegian Directorate of Health and Hospital Construction, Statsbygg, the Norwegian University of Science and Technology, and Verdal Municipality (Trøndelag fylkeskommune, 2023):

"The project aims to ensure that the value of materials in existing buildings remains within the value chain and does not contribute to further climate and environmental impacts. A comprehensive and structured system where reuse is an integral part of the construction industry will help reduce the total amount of waste from building activities and is likely to decrease construction costs gradually."

The partnership cited the newly implemented TEK requirements, specifically § 9-7 as outlined in the Chapter Regulations (2.3), as foundational to the importance of the competition. Additionally, the EU Taxonomy and ISO standards discussed, underscore the significance of these new requirements. DIPLOM aims to develop a digital tool that captures industry momentum by preserving and utilising new data from new constructions, which will be produced and systematised in upcoming phases (Trøndelag fylkeskommune, 2023).

2.7 Material Storage and Digital Platforms

2.7.1 Material Storage: Sirkulær Ressurssentral

To meet certification requirements and facilitate material reuse, the construction industry often needs to store materials temporarily, which demands extensive storage areas. Recently, several initiatives and startup companies have emerged to address this need, with a focus on the sale and storage of reusable materials (Askvik, 2024). One such initiative, based in Oslo, is known as "OMBYGG/Sirkulær Ressurssentral", as depicted in Figure 17.

Figure 17: OMBYGG / Sirkulær Ressurssentral, 0580 Oslo (pictures: author)

The aim of the resource centre is to "*contribute to making reuse the natural first choice in the construction industry, thereby helping to reduce the carbon footprint, raw material extraction, and waste generated by the industry*" (Paadriv, 2024). "Sirkulær Ressurssentral" (Figure 17) is an example of a storage area, which is also starting to be established in many other places in the country.

2.7.2 Platforms for Mapping and Reuse

In Norway, we have several entities aiming to facilitate digital reuse. Several companies have developed their own platforms to provide a standardised tool for their business, in contrast to more manual processes, for example, conducted in "Excel". For instance, "Loopfront" (Figure 18, left image) provides a cloud-based web application that facilitates the reuse, repair, redesign, and recycling of building materials. "Loopfront has developed a digital platform where individuals can list materials and sell them to other individuals" (Loopfront, 2023). Additionally, "Materia" (Figure 18, middle image) has developed a mapping tool aimed at enabling individuals to list materials via their phones for practical reuse purposes (Materia, n.d). Several larger companies have also implemented their internal mapping procedures, and the Norwegian consultancy firm "Asplan Viak" (Figure 18, right image) has developed "delio", a digital tool that enables easy and efficient registration of reused items via mobile or PC in the field, streamlining post-processing information handling (AsplanViak, n.d).

Figure 18: Digital Norwegian Platforms

3 Literature Review

This chapter aims to critically assess the existing literature in the field, providing a solid foundation for further methods. Systematic reviews aim to offer collective insight through theoretical synthesis into the field and its sub-fields (Tranfield et al., 2003). A key characteristic of systematic reviewing is its collaborative nature. Whilst a systematic review can be undertaken by a single reviewer, the quality of the review process is improved by collaboration with others (Torgerson, 2003).

3.1 Literature Search

This Chapter will evaluate various databases through a series of literature search tests. It will also methodically address all components of a systematic review, including formulating a structured search strategy.

Stages of a Systematic Review
A systematic review focuses on using clearly stated, pre-specified scientific methods to identify, select, assess, and summarise the findings of similar but separate studies (Patole, 2021). It also highlights the importance of future research agendas. The chosen stages for the systematic review are as follows:

1. **Defining research problem and question(s):**
   Define focused and relevant problems to address and research questions for the thesis
2. **Identifying relevant work:**
   Identifying, locating and collating results of relevant publications in a systematic way
3. **Develop a search strategy and search the literature:**
   Searching using the developed strategy, usually using pre-planned search words
4. **Select studies for inclusion:**
   Summarise the results of the review in a clearly way and sort the material
5. **Extract all relevant data:**
   Develop a filtering process for all relevant publications
6. **Identifying gaps:**
   New proposals in the context of existing knowledge
7. **Present literature summary:**
   Make recommendations for future research

In conclusion, conducting a systematic review begins with precisely framed questions and involves an objective search and evaluation of relevant literature. This method involves selecting studies based on set criteria, extracting key data, and identifying research gaps, all done to ensure accuracy. The process extends to proposing future research agendas based on identified gaps and presenting the results in a detailed manner. The chosen literature after the filtering process (nr.5) can be seen in Appendix A.

3.1.1 Selection of Databases

Prior to initiating the review stages, a selection of relevant databases was conducted. Multiple databases exist to catalog research publications, such as Scopus, Google Scholar, Oria, and Web of Science. The initial phase of this thesis involved identifying the most appropriate search engines to align with the subject matter of the research. Several search tests were performed to evaluate the efficiency of various search engines. Two search engines were chosen, and search terms were defined. The test searches were conducted on Google Scholar, Scopus, Web of Science, and Oria, using general terms from the thesis topic. The initial search words for testing were:

1. "Construction Industry" AND "Innovation" AND "Material Re-use".
2. "Construction Industry" AND "Point cloud".
3. "Building emissions" AND "laser scan" AND "BIM".

The results showed that Google Scholar had a wider scope, yielding over 10,000 article hits, and Oria had too few hits, ranging between 0 and 40. Web Of Science gained 921 hits on the topic and Scopus had 2322 hits. Scopus has also been recognised as one of the largest trans-disciplinary search engines, publishing articles on construction, built environment, risk management, finance, and economics (Meho and Rogers, 2008). Scopus and Web Of Science also outperformed Google Scholar in terms of more current publications. Therefore, Web Of Science and Scopus were selected as the search engines for the literature searches because of their manageable number of hits prior to the filtering process. After selecting the databases, the search engines were filtered using advanced searches to determine the exact number of literature sources that would be utilised for the thesis.

3.1.2 Operators and Keywords

Boolean Operators
To enhance the precision of the searches, parentheses for connection words and the Boolean operators "AND" and "OR" were utilised. Boolean operators are the bones of any good literature search. These operators tell a database how to combine search terms (Hollier, 2020).

Keywords
The search terms for this thesis were "re-use"/"reuse", "construction", "buildings", and "laser scan". These words are central to the research of the thesis. The words "re-use"/"reuse" and "construction" were chosen to be connected with an operator, as were "buildings" and "laser scan". After testing, this combination proved optimal as it yielded a substantial number of hits. Since these are not two terms commonly researched together, an operator was used between them to extract research related to each word individually. Final search terms, combinations and amount of articles can be seen in table 4.

Table 4: Search words and hits in the chosen databases.

Final Search Words	Web Of Science	Scopus
"re-use" AND "construction" OR "buildings" AND "laser scan"	921	2,322

3.1.3 Search Strategy

The methodology incorporated two distinct stages: firstly, the selection of review samples, and secondly, an in-depth content analysis of these samples. The process and criteria for selecting the review samples are detailed in Figure 19. Given that the literature search focuses on two distinct areas (reuse and digitalisation), the final articles were entered into an Excel document and characterised based on keywords. The Excel document can be seen in Appendix A.

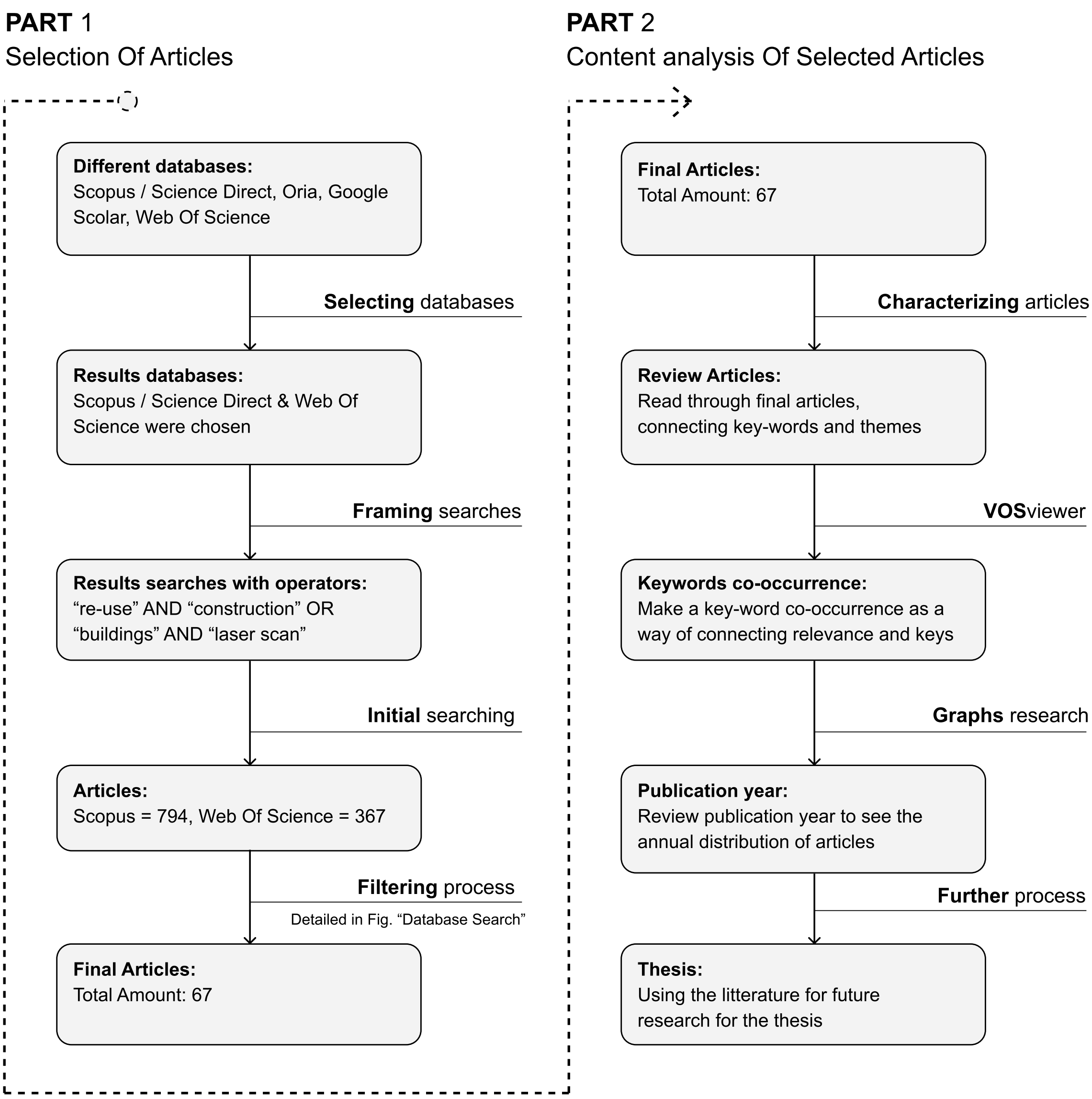

Figure 19: Selection of Articles, study flowchart, Part 1 and 2 (produced by author adapted from Long et al., 2024)

3.1.4 Final Search

The results from the final searches were filtered down to a manageable number based on various criteria, as shown in Figure 20. The final search yielded 67 hits, which will form the basis for further exploration. It was crucial to emphasise both reuse and sustainability as perspectives, in addition to laser scanning, to gain a deep enough understanding of how these elements currently function. This approach facilitates further research into combining digitalisation and sustainability as an effective method for mapping buildings. The final 67 hits can be seen in Appendix A.

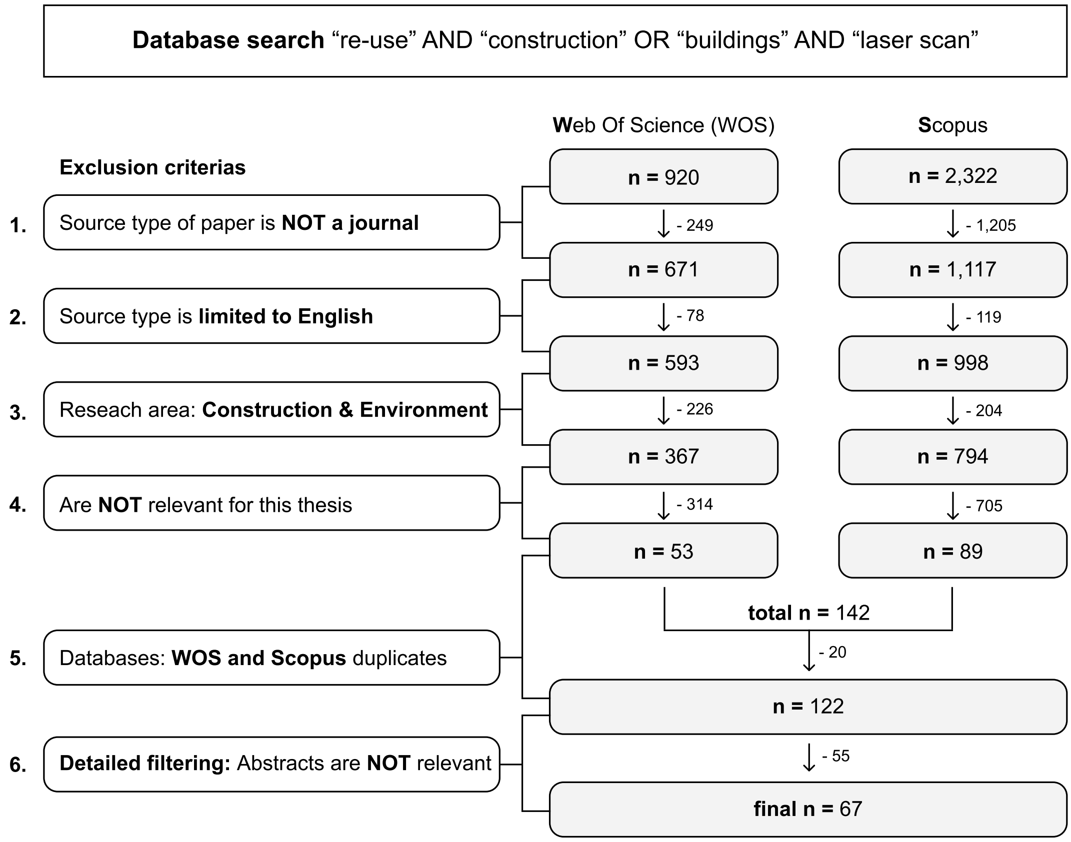

Figure 20: Chosen filtering process for all relevant publications. The final hits were 67 and can be seen in Appendix A.

Year of Publication

Figure 21 clearly indicates a growing trend in sustainability and digitalisation. This graphic represents the publication years of selected studies for the literature review. The thesis incorporates 10 articles spanning from 1981 to 2010. Despite an initial focus on contemporary relevance, the inclusion of earlier work provides a comprehensive understanding of the subject's evolution. The rising trend in sustainability and digitalisation emphasises their contemporary importance and further validates the thesis's relevance for future research.

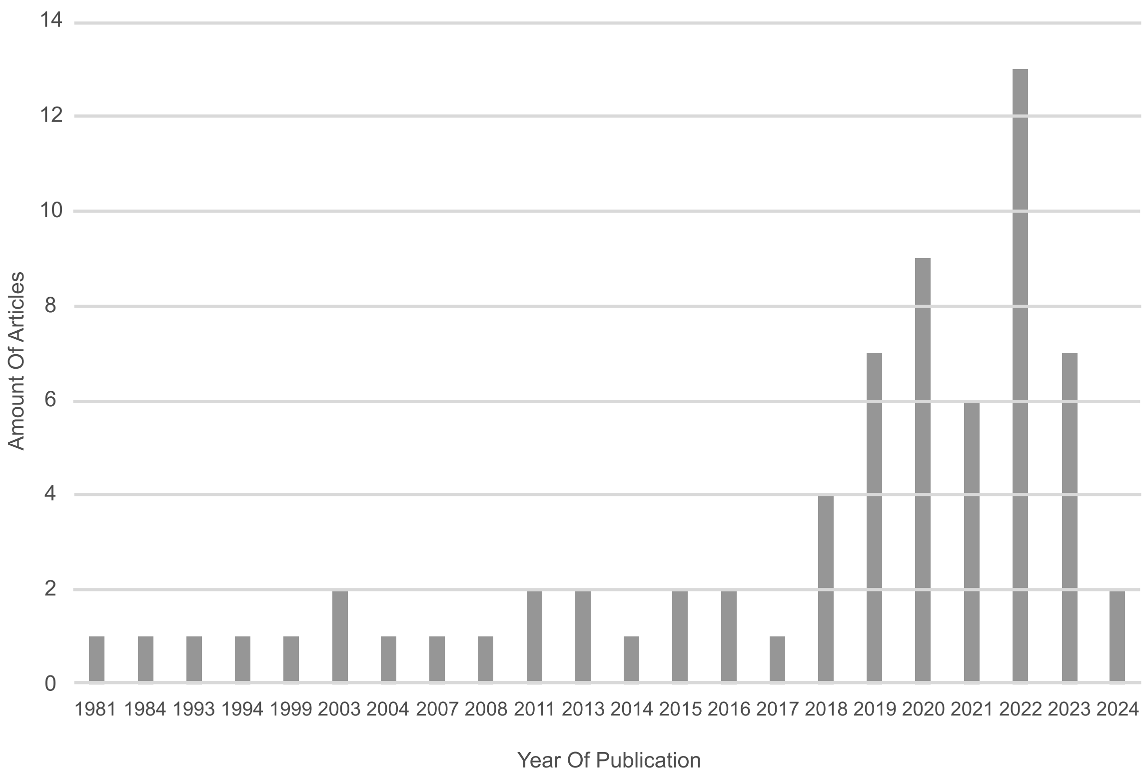

Figure 21: Chosen literature for the review and their year of publication.

Keywords Co-occurrence Network

As seen in Figure 22, VOS viewer is used to discover connections through visual analysis. The articles selected in the literature search have been input into the program, and the dataset has been used to visualise the co-occurrence patterns of keywords or terms within a dataset.

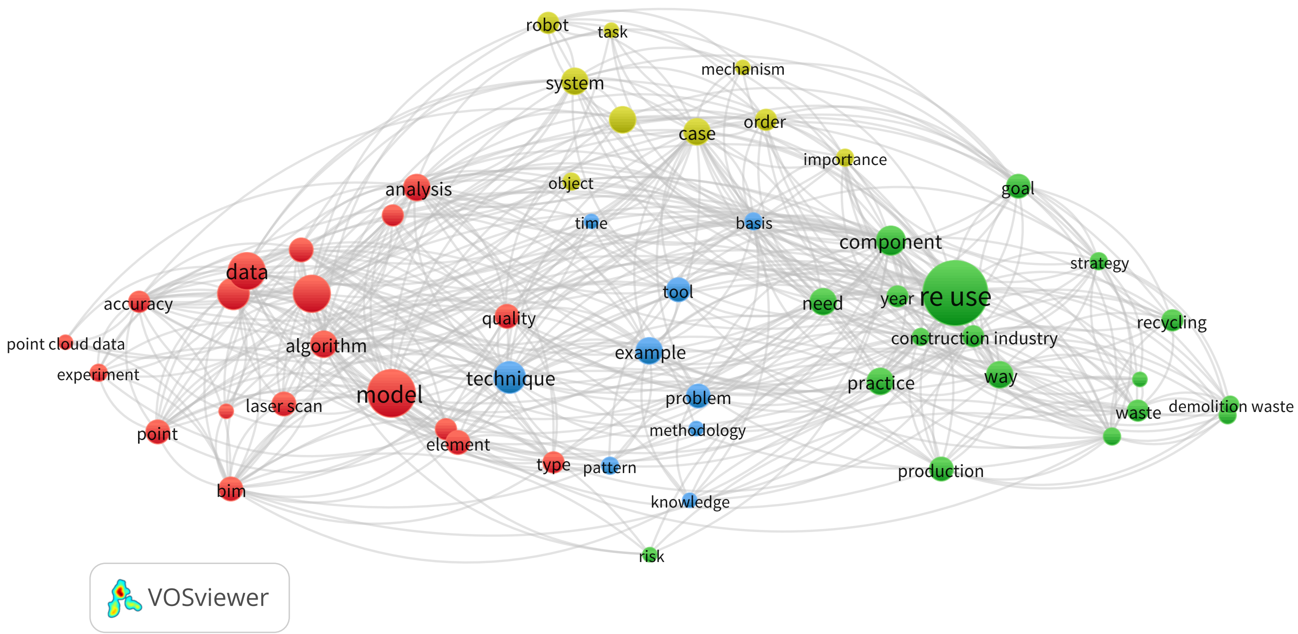

Figure 22: The keywords from the co-occurrence network made using VOSviewer (2023).

3.2 Validity and Reliability

The evaluation of the sources was undertaken using the TONE principle, a method recommended for source criticism at NTNU, as seen in Table 5. This approach is centred around four crucial terms, each playing a vital role in the analysis of the information provided by the source (Overland, 2018). For each keyword, there are corresponding questions focusing on whether the literature is peer-reviewed, originates from reputable publications, is presented in a suitable and unbiased manner, and has relevance to a specific time period.

Table 5: The TONE Principles by Overland (2018).

Letter	**Principle**	**Topic**	**Synonyms**
T	Trustworthiness	• Is the source reliable and unbiased?	Reliable
		• Who is the author?	Upright
		• Who is the sender?	Honest
		• What references are listed?	Secure
O	Objectivity	• How is the information presented?	Neutral
		• Is there consistency with other sources?	Impartial
		• Are multiple perspectives illuminated?	Independent
		• Is the information conveyed neutral?	Objectively
N	Necessity	• When was the source last updated?	Accurate
		• Are there any signs of carelessness?	Precise
		• Does the author cite their sources?	Consistency
		• Is the research methodology verifiable?	Thorough
E	Evidence	• Who is the target audience?	Useful
		• Does the source fit the purpose?	Valuable
		• Is the source easily accessible?	Relevant
		• Are the data and information relevant?	Applicable

The TONE principles were incorporated into the filtering process during the searches. As mentioned in the limitations (Chapter 1.3), a notable weakness in the literature is its international scope, which can be problematic since regulations and the construction industry vary significantly between countries, reflecting differences in culture and climate. Consequently, it was decided that the theory chapter should primarily focus on Norwegian literature to align with the findings derived from the TONE principles.

3.3 Literature Summary and Gap Identification

Linking the searches "reuse" and "laser scanning" with an "AND" operator made it possible to look at two different areas, which to this day have not been discussed much together. The articles about the specific new technologies were read in detail, in combination with the articles about the reuse market and the industry of the future. In this Chapter, the literature will be described, combined with essential quotes taken from the literature. Finally, key gaps will be identified in the form of bullet points. The figures from 1-67 shown in Appendix A describe the year of publication of the literature, with the most recent at no.1 and the oldest at no.67. The specific year is shown in column 2 from the left, called "YEAR".

3.3.1 Literature Findings

Building Information Modelling and Laser Scanning

A substantial portion of the literature on laser scanning and digital development examines the potential uses of BIM (Building Information Modelling) technology and laser scanning for old buildings. Lee et al. (2021) explore point-cloud technology and conclude that its unfamiliarity to many architects hinders its widespread adoption, as many professionals in the field are not yet familiar with it. Xu and Chen (2020) believe that 3D laser scanning technology can quickly collect point cloud data of measured buildings and "significantly reducing the workload involved in surveying and mapping". Despite this, the creation of as-is BIMs from laser scan data, known as scan-to-BIM, faces challenges due to the vast amounts of data generated. According to Qiu et al. (2022), scanning a small room can produce hundreds of millions of points in minutes at high resolution, making it difficult to distinguish critical features like edges and labels. Additionally, processing this large dataset is time-consuming and burdens storage and computing resources. Therefore, down-sampling the raw laser scan data is necessary for more efficient processing.

Ding et al. (2019), argues that integrating Environmental Product Declaration (EPD) and Life Cycle Analysis (LCA) data into BIM can enhance communication and documentation of material and product specifications, including their location and disassembly guidelines. This information aids decision-makers and designers in selecting materials and products designed for reuse and recycling within closed material loops, aligning with CE design and construction principles.

"For the buildings with repetitive elements and that can be classified, the scan to BIM is an optimal technique evaluating time and resources. Since it has human interpretation, uncontrolled errors by automatic processes are avoided and the instrumental error is optimised."(Corso Sarmiento et al., 2019)

Building Information Modelling and Artificial Intelligence

Along with laser scanning and the resultant dataset, several articles have delved into various algorithms aimed at automatically converting 3D points into positions that enhance a digital model with more data than what is currently feasible (Xiong et al., 2013). Applying artificial intelligence (AI) algorithms has the potential to boost the BIM model's capability to process data and recommend more efficient and environmentally sustainable adaptive reuse solutions (Cinquepalmi et al., 2023). Kim et al. (2018), challenged the efficiency of down-sampling raw laser scan data with a registration process to merge multiple scans covering all construction site areas. The result was a proposed framework using feature detection algorithms commonly applied in computer vision to identify geometric correspondences among the series of scans for the initial alignment. Ogunmakinde et al. (2022) address slow development as a main issue and mention that digital technology still has limited diffusion in the construction sector. There is a correlation between the articles' publication years and their relevance to point cloud data. The later an article is published, the higher the percentage of it containing information about point cloud data. This indicates that this technology is new and advancing rapidly.

"In addition to the integration of BIM (Building Information Modelling), the use of advanced sensors and Internet of Things (IoT) devices could further enhance the data collection and analysis process."(Cinquepalmi et al., 2023)

Different authors have also explored the possibility of combining different terms and technologies. Ding et al. (2019) explored reversed engineering (RE), which means dismantling an object to see how it works, and argues that by using RE, the combination of BIM and RE technologies improved the information utilisation among all the professionals in different phases.

Reuse
In the field of reuse, several studies have been conducted on different cases that look at how such a process has taken place. Comparisons between different buildings have led to a result that says that adaptive reuse, unlike constructing a new one, must begin with an in-depth analysis of the existing building, its potential, and stakeholder needs (Shin, 2023). Aigwi et al. (2022) investigated further how this can be done, and some have created a framework that ensures guiding relevant stakeholders on how the reuse of existing buildings can be used as a practical, sustainable measure. In addition to this, in a case study conducted in the Netherlands, obstacles to initiating circular thinking in construction projects were identified, including insufficient information, technical complexity, shortage of circularity expertise, and a scarcity of innovative circular solutions (Hamida et al., 2022).

"It is not enough to focus on closing material loops to create new products from today's waste streams without care for the overall scale of resources used."(Foster, 2020)

In addition to reuse, the focus on waste and deconstruction is a widely discussed topic in the literature. Several articles examine disassembly routines, arguing that developing an appropriate deconstruction project plan is a crucial step for improving the outcomes of adaptive reuse projects (Sanchez et al., 2019). Systematic implementation of different principles and practices for materials, such as changes in logistics and different material schemes, is said to "improve resource efficiency and reduce environmental impact by reducing waste generation, minimising transport impacts and maximising reuse and recycling" (Galvez-Martos et al., 2018). Kunieda et al. (2019) created a time-lapse evaluation model through a computerised 4D motion workflow simulation aiming to contribute to more efficient demolition projects. They argued that "demolition modelling can help direct professionals in the right direction to make informed decisions" (Kunieda et al., 2019).

Circular Economy
In addition to the growing body of literature on point clouds in digital development, there is also a clear and frequent mention of the CE in more recent literature. As discussed in Chapter 2.5, this term remains relatively new, with ongoing developments in legislation mandating industries to address this issue. Several of the articles point to the need for parameters and indicators that measure the degree of sustainability of different forms. For example, it is mentioned that measuring

the circular economy in the project could make a positive contribution as well as influence other projects in the same direction (Dişli and Ankaralıgil, 2023).

"The process of planning and building according to CE principles currently still shows many administrative, financial, legislative and physiological hurdles which need to be reduced quickly in order to allow a paradigm shift."(Heisel et al., 2019)

Another study by Nadazdi et al. (2022), investigated the circular economy in construction and demolition waste management, examining the opportunities and barriers associated with adopting circular economy principles in the built environment. The study identifies barriers to the adoption of circular economy approaches in construction and demolition waste management, such as underdeveloped markets for recovered materials and the low prices of raw materials (Nadazdi et al., 2022). This issue, in conjunction with the argument that existing sustainability assessment models seldom incorporate all three pillars of sustainability (environmental, social and economic), complicates the development of a circular economy.

"It is recommended that circular economy is integrated in all phases of construction, including the pre-construction and post occupancy stages. In addition, all stakeholders who generate waste should apply new innovative technologies, methods and strategies leading to transdisciplinary and transformative change."(Ogunmakinde et al., 2022)

3.3.2 Gap Identification

In this Chapter, gaps identified in the literature will be outlined in bullet points. These points will serve as the defining factors for the selection of methodology and case studies in this thesis.

- The articles extensively research both digitalisation and the reuse of materials. This comprehensive analysis is achieved through in-depth explorations of new technology, circular economy principles, and development strategies. Yet, there is still a notable gap in research that combines digital advancements with sustainable development. Few studies have effectively integrated these two critical aspects, highlighting an important area for future investigation and innovation.
- Few of the articles offer comprehensive solutions or definitive conclusions addressing the economic challenges linked to the issue of reuse. Although these studies often mention economics as a potential problem, they do not offer practical strategies or useful insights.
- The literature presents various research methods, with interviews being one of the approaches. However, none have conducted interviews comprehensively across the entire industry to identify common solutions to the challenges of reuse and digitalisation. This lack of extensive industry-wide engagement has resulted in an unclear understanding of the issues and a lack of unified solutions that address both reuse and digitalisation effectively.
- As mentioned in subsection 3.2, none of the literature is entirely Norwegian. This could be a weakness in the study, but it could also indicate a need for more research focusing on the Norwegian industry.

- Based on the literature, research on datasets is increasing, but significant challenges remain in handling large volumes of data in scanning processes. Research on down-sampling raw laser scan data is necessary for more efficient processing.
- Several articles mention the need to construct using materials suitable for disassembly. Others highlight the challenges related to emissions from new materials. These areas are rarely combined, underscoring the need for integrated approaches that address both new materials and environmental impact.
- Several studies examine regulations for materials, but none have proposed what should be changed. This leaves a significant gap in the research, as identifying necessary regulatory adjustments is crucial for advancing material reuse and sustainability efforts.
- Several articles examine waste and demolition management, yet further research is needed regarding which stakeholders are responsible for this area and their perspectives.
- The concept of circular economy is increasingly referenced within the context of the construction industry. It is crucial to explore how this concept can evolve alongside the construction industry's development to uncover potential correlations and synergies between the two.

4 Methodology

This chapter provides the research framework foundational to the thesis, providing a detailed explanation of the research design and the methodologies employed. It explicates the strategies and techniques implemented for data collection, covering all methods employed to investigate the research questions. Finally, the analysis technique of all the methods used will be presented.

4.1 Research Framework

To visualise the structured approach to the research, Figure 23 illustrates the steps from the resources used to the long-term impacts aimed to achieve. The diagram underscores the connectivity and progression from inputs to impacts, highlighting how each step is intentionally designed to build upon the previous one (W.K. Kellogg Foundation, 2004). This structured progression ensures results that are applicable in both academic and industrial fields. The different areas of the framework in Figure 23 are explained below (W.K. Kellogg Foundation, 2004):

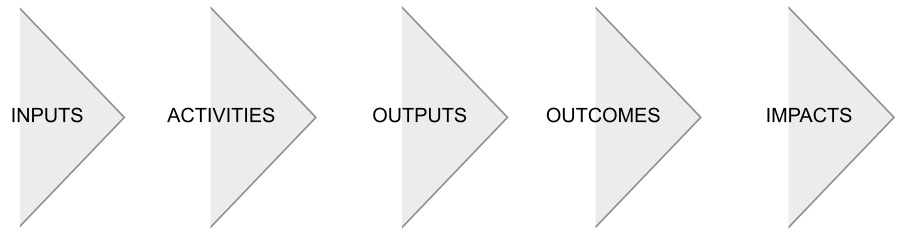

Figure 23: Chosen Logical Model Framework (W.K. Kellogg Foundation, 2004)

- **Inputs**
  Definition: Resources that are invested in the research project.
  Information Needed: Details about research time, personnel, equipment, data sources.
- **Activities**
  Definition: Actions undertaken with the inputs to conduct the research.
  Information Needed: Specific actions you will take to conduct the research.
- **Outputs**
  Definition: Direct products of the activities done.
  Information Needed: Compiled datasets, number of activities completed or conducted.
- **Outcomes**
  Definition: Medium-term effects of the outputs, reflecting changes.
  Information Needed: Expected outcomes.
- **Impacts**
  Definition: Broader or long-term effects of the project.
  Information Needed: Long-term impacts.

The framework outlined all the procedural steps of the task, with Figure 24 providing a detailed summary of the activities to be undertaken at each stage. This framework established the foundational basis of the task, which subsequently guided the development of additional methodologies.

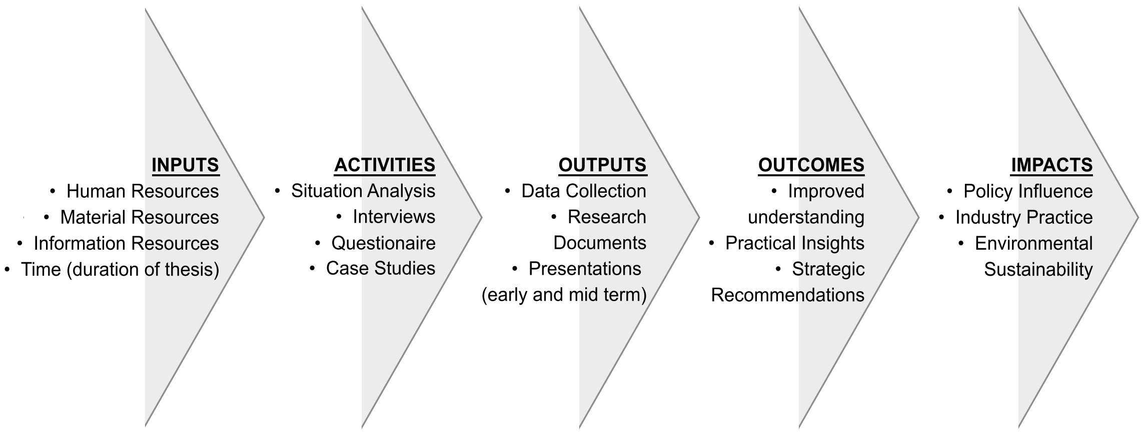

Figure 24: Structure Logical Model Framework: Thesis (W.K. Kellogg Foundation, 2004)

"The Research Onion" by Saunders (2018), was employed to further define the steps developed using the logical framework and can be seen in Figure 25. This model depicts a potential design structure composed of five distinct layers, of which three are utilised in this thesis. Stages 1, 2, and 3 defined in Figure 25 delineate the "inputs" and "activities" from the logical framework. The core, labelled "Data Collection and Analysis" corresponds to the data gathering and analysis efforts conducted by the chosen design (AESA, 2020), and aligns with the 'outputs' stage of the logical framework in Figure 24. The methods selected for this study are highlighted in bold and will be detailed in the subsequent chapters.

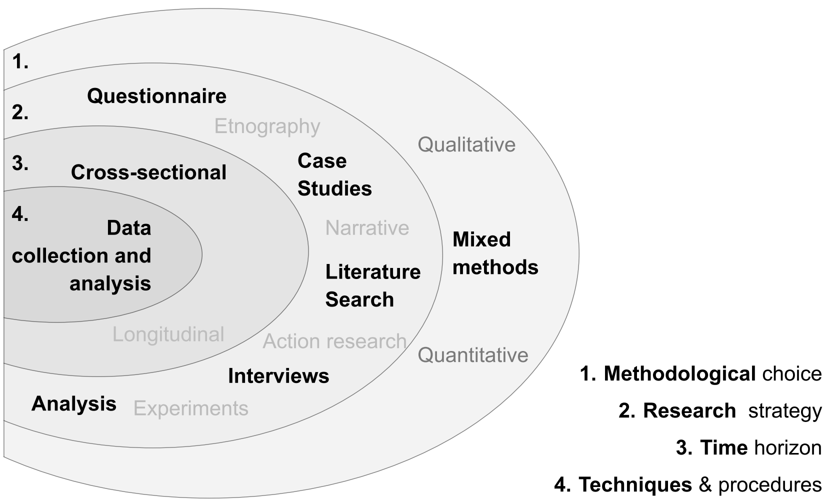

Figure 25: The Research Onion (Saunders, 2018)

4.1.1 Methodological Choice

In research, a distinction is made between qualitative and quantitative methods (Marczyk et al., 2005). The chosen research approach for this thesis is divided and is called "mixed methods" as seen in Figure 25. While quantitative methodology involves the collection of data, often encompassing specific variables in the form of numbers and statistics (Dalland, 2021), qualitative methods collect data in textual form and typically involve detailed data from individuals or organisations.

Therefore, "mixed methods" is chosen because the research questions are largely dependent on both statistical data and the more qualitative opinions, experiences, and practical approaches explained in Table 6. This allows for an industry overview based on statistics and an in-depth examination of a limited number of cases, capturing the subjective perspectives within the field.

Table 6: Quantitative and qualitative methods.

	Research Questions	**Quantitative**	**Qualitative**
1.	How do stakeholder roles and interactions influence the effectiveness of material reuse strategies in the construction industry?	X	X
2.	What early-phase mapping solutions have been developed to date and how do these function in practice?	X	X
3.	How can we facilitate increased reuse in the industry during the early stages of the project?	X	X

4.1.2 Research Strategy

The selection of a research method defines the basic approach, while the research strategy details the execution plan for addressing the main and associated research questions (Saunders, 2018). The research strategy section will explain the five primary methodologies employed: situational analysis, literature search, questionnaire, case studies and interviews. This layer guides the selection of the most appropriate research method. Chapter 4.2 will detail the specific methodologies employed and describe how the data collection was conducted. Figure 26, displays a timeline of all components in the methodology.

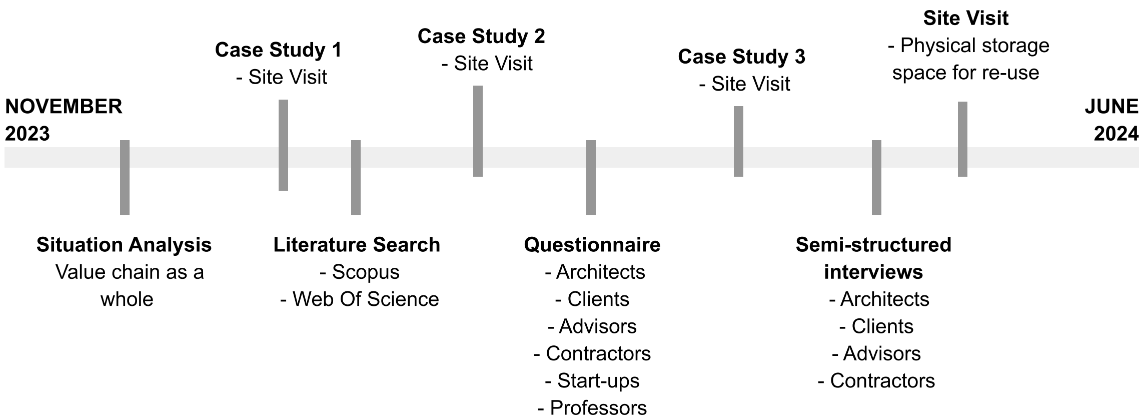

Figure 26: Timeline methodology

Situational Analysis

For the quantitative part of the thesis, the strategy involved doing a "Situational Analysis" to gather data. Various actors in the construction industry responded to a quantitative study, laying the groundwork for further qualitative investigations.

Literature Search

A structured literature search was conducted to identify gaps in the existing literature, as seen in chapter 3.

Case Studies
Considering the complexity of the construction industry, conducting several case studies on construction sites was essential to understand the practical aspects of sustainability and reuse. Therefore, case studies are employed as a research strategy to address the three selected research questions. Studies can be seen in Chapter 4.2.4.

Questionnaire
A questionnaire was chosen to be conducted after the Situational Analysis to obtain generalised and comparable findings. The target group for the questionnaire included all professional departments involved in a construction project: architects, builders, contractors, startup companies, consultants, etc. The procedure is explained in Chapter 4.2.2.

Interviews
The interview questions for the final stage were developed from insights acquired through preceding methodologies. This strategy ensured the validation of theoretical concepts and questionnaire data, offering a detailed exploration of the interviewees' perspectives and experiences. The procedure is explained in Chapter 4.2.3.

Triangulation
Triangulation refers to a research strategy to test validity through the convergence of information from different sources by providing a more comprehensive understanding of the subject (Carter et al., 2014). This study incorporates a three-part triangulation approach as seen in Figure 27. Firstly, a literature review establishes the theoretical background and context, identifying gaps in existing literature. Secondly, interviews and questionnaires provide depth through both qualitative and quantitative data, offering insights and perspectives from individuals directly engaged with the research area. Finally, case studies allow for a detailed examination of specific examples relevant to the research questions, applying theoretical concepts to practical scenarios.

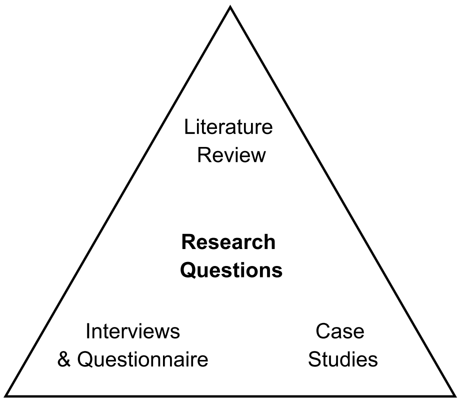

Figure 27: A method to enhance the credibility and validity of the research findings called "Triangulation" by Carter et al. (2014).

Using these methods has been beneficial for the validity of the study. Each method has contributed essential knowledge to the thesis within its area. As shown in table 7, the research questions are linked to different methods to achieve comprehensive answers. The table demonstrates that all of the methods are used on all three research questions.

Table 7: Chosen research strategy with methods used.

Research Questions	Literature Review	Case Studies	Interviews or Questionnaires
How do stakeholder roles and interactions influence the effectiveness of material reuse strategies in the construction industry?	X	X	X
What early-phase mapping solutions have been developed to date and how do these function in practice?	X	X	X
How can we facilitate increased reuse in the industry during the early stages of the project?	X	X	X

4.1.3 Time Horizon

As depicted in Figure 25, the time horizon can be divided into two categories: cross-sectional or longitudinal. This means whether the observations to be analysed are a snapshot in the present or are to be conducted over a longer time period (Saunders, 2018). Due to the time constraints of this thesis, a cross-sectional approach has been chosen. Analyses will be conducted at one point in time, which may influence the results of the thesis. Construction projects usually span several years depending on their scale, which means the projects can experience significant fluctuations in cost, workforce, timeline, resource availability and other topics. Since the thesis employs both quantitative and qualitative methods, it will be able to gather data based on experiences and subjective perceptions, fitting well with the chosen cross-sectional approach.

4.2 Data Collection and Analysis

Methods and Technique

Within qualitative data collection, several interview methods exist to choose from (Tjora, 2017). Interviews can be divided into three main categories: structured, unstructured, and semi-structured interviews. The name indicates the degree of rigidity imposed on the interviewer by the interview guide. A dual approach to interviews was employed to determine the thesis topic. Initially, a situational Analysis (Part 1 in Figure 28) was conducted, aiming to identify critical challenges within the construction industry. Part 2 in Figure 28, was conducted to collect qualitative data from key industry people within the topic area by employing semi-structured interviews as the method. For the quantitative part, a questionnaire was created. The questions were developed using the results from the situation analysis.

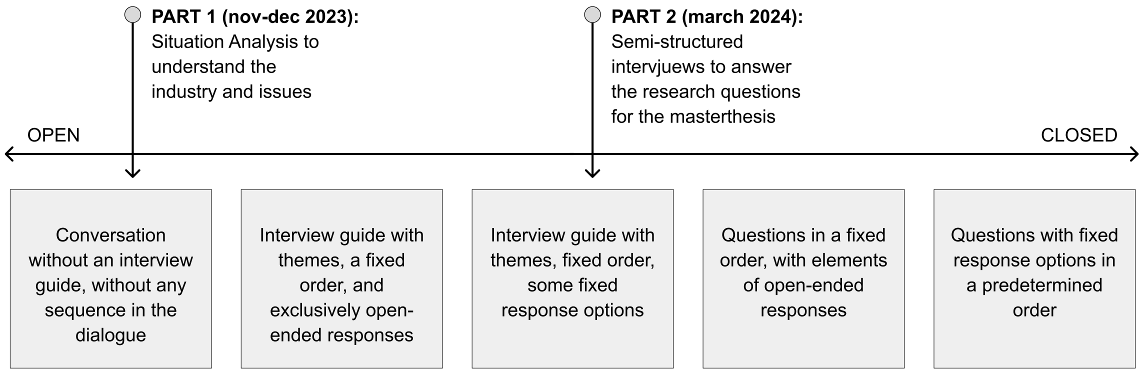

Figure 28: Different qualitative interview structures by Jacobsen (2015))

4.2.1 Situational Analysis

The situational analysis conducted in January 2024 was instrumental in defining the thesis topic. During this period, key figures in the construction industry were contacted to obtain an insider's perspective on project execution and the primary challenges within the sector. This was carried out through phone calls, which varied in duration from 5 to 60 minutes. Maintaining an open dialogue without predetermined direction was essential, to allow the conversation to unfold organically. During the conversations, it was early on observed that regulations, sustainability, and reuse were significant topics meriting deeper investigation. This insight established the groundwork for further research. The detailed results from the analysis will be presented in chapter 5.The initial set of questions posed in the preliminary discussions were formulated as follows:

- Could you describe your role in a construction project?
- What do you perceive as the most significant problems in the construction industry today?
- What information or solutions would assist you in improving the quality of your projects beyond your current capabilities?
- How do you envision the future of construction projects?

4.2.2 Questionnaire

A questionnaire was conducted to collect data for the quantitative part of the mixed-method approach. To address all research questions, 27 questions spanning various categories were created, ensuring relevance across all disciplines and enabling data comparison on a uniform basis. Of the questions, 16 were mandatory, whereas 10 were contingent upon the responses given to preceding questions. The entire questionnaire is included in Appendix B.

Various response types were chosen depending on the questions posed. The options included single choice, multiple choice, linear scale (1-5), and free format. Single choice, multiple choice, and linear scale are helpful for data comparison. The final question was an optional text field intended for supplementary reflections on the subject matter. This design was chosen to ensure that all respondents with relevant information could easily provide feedback not specifically covered by the structured questions in the questionnaire.

The questionnaire was structured to require between 5 to 10 minutes for completion. Three preliminary test questionnaires were distributed to assess comprehensibility and length, with feedback indicating the need for simplification and shortening. Additionally, there was a preference for translation into Norwegian, the general language of the industry. The final questionnaire included both Norwegian and English translations for all 27 questions and response options. The informants were contacted via the author's network, industry partner and social media. The questionnaire was also shared in several social media groups and through contacts and earlier theses, as seen in Figure 29, and explained underneath the Figure.

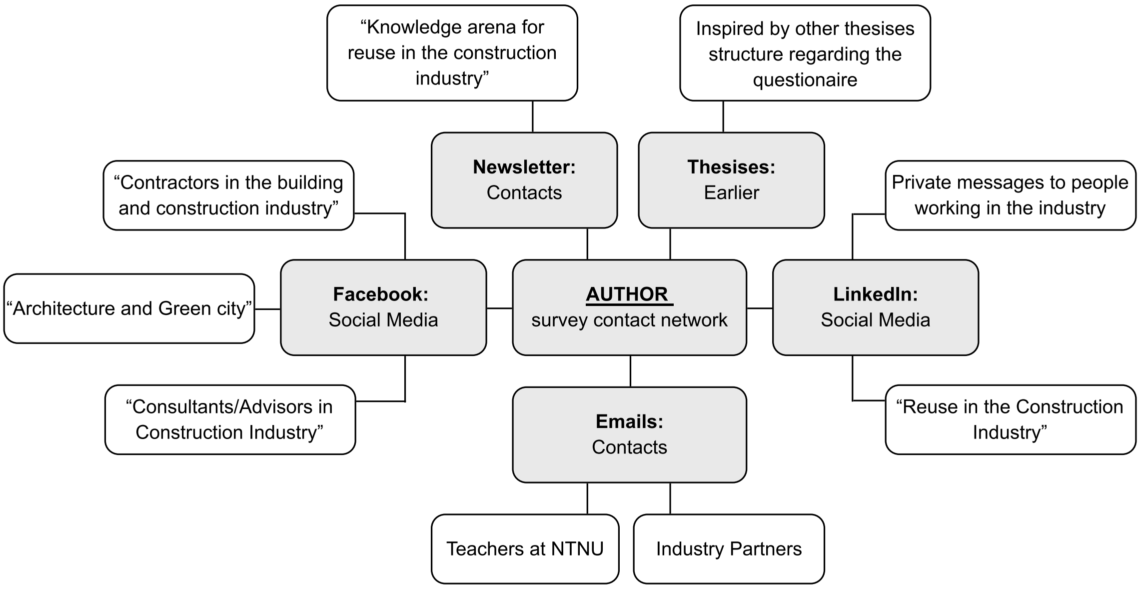

Figure 29: Questionnaire contact network

- **"Reuse in the Construction Industry"** LinkedIn, found through searching
- **"Contractors in the building and construction industry"** Facebook, found through searching
- **"Architecture and Green city"** Facebook, found through searching
- **"Consultants/Advisors in Construction Industry"** Facebook, found through searching
- **"Knowledge arena for reuse in the construction industry"** Newsletter
  I obtained contact information for a construction industry newsletter through a teacher at NTNU. I was permitted to include the link to the questionnaire in the April 2024 newsletter, which was distributed to all subscribers.
- **Earlier thesises** NTNU
  Through my supervisor, I obtained access to prior master's theses addressing the same topic.

The questionnaire was structured the following way:

Background: Section 1-8

Questions 1-8 were mandatory or conditional, dependent on previous responses, focusing on the informant's background. These questions included inquiries about gender, age and country of employment, offering insights into patterns of experience and motivational factors. It was essential for the findings to compare industry roles with viewpoints on the thematic content.

Earlier project and motivation: Section 9-13

Then, the questions focused on the informant's previous projects and their involvement in reuse initiatives. This established the foundation for follow-up questions about their motivations, which are only posed if they indicate prior involvement in reuse projects.

Role and main challenges: Section 14-17

This section addressed the primary challenges within the industry, offering respondents a selection of options to capture the complexity of the issue. Additionally, respondents were given a text field to provide further clarification on their perspectives regarding these challenges.

Barriers and Drivers: Section 18-20

This section gave the informant the opportunity to choose on a scale between barriers (1) and drivers (5) regarding the extent to which they perceive areas for reuse. This ensures that the task covers the entire industry and its specialised fields.

Regulations and Digitalisation: Section 20-27

Lastly, this section explores opinions on digitalisation and regulations, emphasising their potential impact on future construction projects. Participants have the opportunity to express agreement or disagreement regarding the influence of regulations and digitalisation on the construction industry of tomorrow. Additionally, informants can provide further insights in a provided text field.

Validity and Reliability

This approach of making a questionnaire can be described as a purposive sampling method, meaning it involves intentionally selecting individuals who meet specific criteria for inclusion (Jacobsen, 2015). For this study, it meant specifically contacting individuals employed in the construction industry. A potential limitation of this method is that the sample may not be fully representative of the population. This is especially important for the thesis as it covers multiple disciplines, which could lead to an imbalance in subjective viewpoints and expertise areas. It was also crucial to categorise which sector of the industry each respondent belonged to. In certain instances, respondents were limited in the number of alternatives they could select. This measure was introduced to ensure respondents thought carefully about their choices and highlight the importance of their preferred options. Additionally, the number of questions and the extent of the questions should also be considered to ensure that the motivation of the respondents is not compromised (Johannessen et al., 2021). To ensure the validity of the respondents, a control question was included to verify their attentiveness during the questionnaire. The mandatory question 12 was formulated as follows:

"If you are paying attention to the questionnaire, please choose option 4 on the linear scale."

Incorporating this control question enables the exclusion of participants who answered it incorrectly, as Google Forms allows access to individual responses after submission. This ensures that their other responses are not included in the data collection, helping to guarantee the authenticity of the collected data.

4.2.3 Semi-Structured Interviews

Semi-structured interviews were conducted for the concluding part of the interviews. Semi-structured interviews are typically used when the objective is to explore attitudes, opinions, and experiences (Tjora, 2017), and were therefore the right fit for this thesis within the construction industry. These were more focused than earlier interviews, with only a selected group of informants chosen. Semi-structured interviews are particularly suitable when there are relatively few interview subjects, and there is a special interest in the information that the informant can convey (Jacobsen, 2015). The interviews were structured around findings from earlier research and targeted areas identified for deeper investigation, stemming from identified gaps in the literature. A pre-designed interview guide with a fixed order of open-ended questions was used. All questions were open, allowing respondents to freely choose the aspects they wished to highlight (Bogner et al., 2010). The interview guides were developed together with the established research questions and can be seen in appendix C. Table 8 shows the interviewees and their position, area and firm.

Table 8: Interviewees: position, area of knowledge and firm.

Interviewee	Position	Area	Firm
O1	Architect	Transformation	Nordic Office of Architecture
O2	Architect	Transformation	Nordic Office of Architecture
O3	Head of ScanToBIM	Transformation	Norconsult
O4	Operations manager	Transformation	Norconsult
O5	Advisor	Sustainability	Norconsult
O6	Project Manager	Building Owner	Trøndelag Fylkeskommune
O7	Project Leader	Physical Storage	Sirkulær Ressurssentral
O8	Architect	Sustainability Advisor	Nordic Office of Architecture

The interview subjects represent a broad spectrum of early-phase knowledge within the industry. The industry partner has facilitated access to suitable candidates from both architectural and advisory backgrounds. To ensure comprehensive coverage of the topic, the remaining interview subjects are individuals within the industry possessing extensive knowledge and holding influential positions.

Execution

Prior to each interview, participants were provided with the questions and thesis details (Appendix C). They were also informed about the necessity of consenting to audio recordings. Most interviews were conducted face-to-face in the interviewees' offices, improving the discussions' quality and facilitating interaction with employees from different locations. Interviews that were not feasible to conduct in person due to geographical constraints were held using the platform Teams. This platform's camera and audio features were utilised to maximise trust and openness, essential for enhancing the quality of the conversations (Jacobsen, 2015). Each interview was scheduled for one hour, and typically, the duration was close to 60 minutes, although some interviews extended beyond this period. Following each interview, time was set aside for transcription, allowing for timely reflection on the discussion while the details were still clear in memory.

Validity and Reliability
An interview guide with chosen topics and questions was essential to gather data that is most relevant to the research question. The use of semi-structured interviews presents specific challenges, particularly in the necessity to adapt follow-up questions. This is because each person's personal experiences affect their answers, which might lead them to focus on different topics. Therefore, a strategy for follow-up questions aligned with the thesis's research objectives was made. This approach facilitates a deeper and more focused exploration of the subject matter.

4.2.4 Case Studies

Three case studies have been selected to provide projects for reference, drawing from the information and theory previously presented in the thesis. The chosen studies are transformation projects. The studies were selected based on recommendations from the industry partner (Nordic Office Of Architecture), and several of the interview subjects presented in chapter 4.2.3, are involved in the selected case studies. This involvement provides a valuable connection to the practical applications and insights from those actively engaged in the cases being examined. This offers a chance to deeply explore a phenomenon within a particular context (Yin, 2014) and to ask follow-up questions to those involved. This approach allows for a detailed examination of specific changes and their impacts within the companies. The studies chosen are three different building projects, each in varying stages.

A commonality among these projects is the attempt to implement reuse. The objective of these studies is to observe how various reuse decisions have impacted the projects, both positively and negatively. The chosen studies can be seen in Table 9.

Table 9: Chosen case studies.

Name/Address	Owner	Stage	Transformation Project
Odins Gate 4, Oslo	Oslo Kommune	Under Construction	X
Bærum Kommunegård	Bærum Kommune	Finished	X
Spor X, Drammen	SEN KS	Finished	X

Case Study 1

Adress: Odins Gate 4, 40266 Oslo
Owner: Oslo Kommune
Architect: Nordic Office of Architecture / Norconsult
Project Description: Transformation project
Stage: Under Construction
Date visited: 22.01.2024, 10.04.24, 16.5.24

Odins Gate 4 (Figure 30) is a project by the Oslo Municipality aimed at housing Ukrainian refugees in the Frogner area of Oslo. The building consists of eight apartment complexes and a backyard. Nordic Office Of Architecture has been engaged as the architect for this transformation project, which is currently in the construction phase. The initial goal was to incorporate reuse principles wherever possible. A challenge encountered was the discovery of “Serpula lacrymans” (house rot). The result was spending several million kroner on removal, funds that had to be reallocated from other areas. This impacted the project’s reuse potential, as there was no budget left for expensive decisions.

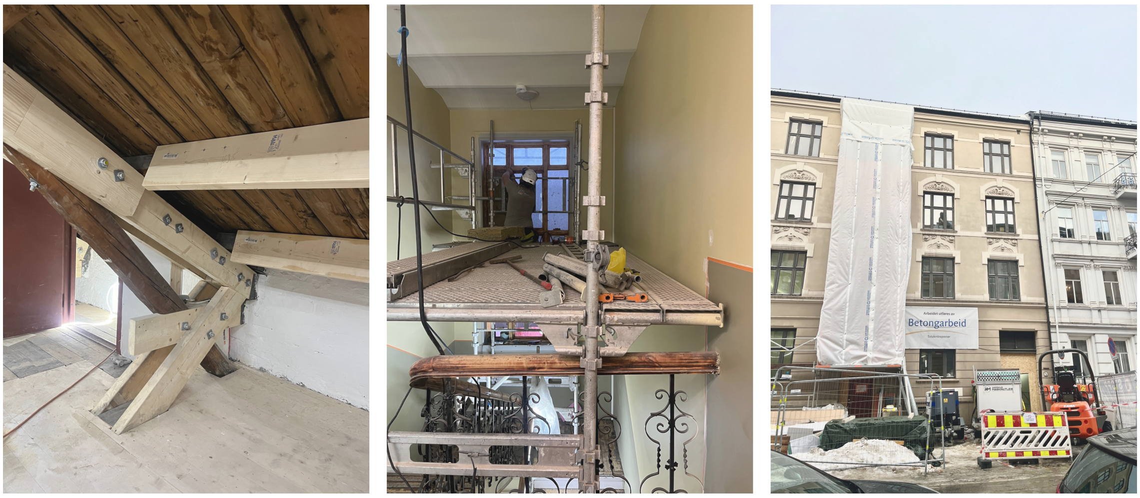

Figure 30: Odins Gate 4, 0266 Oslo

Case Study 2

Adress: Arnold Haukelands plass 10, 1338 Sandvika
Owner: Bærum Kommune
Architect: Pilot Arkitekter and SIGNAL Arkitekter AS
Project Description: Transformation project
Stage: Finished
Date visited: 08.04.24

The old municipal building “Bærum Kommunegård” (Figure 31) before the transformation was completed in 1990. According to Blakstad (2024), the building consisted of two blocks connected by a glass-covered central hall at that time. The municipal building underwent a renovation, and the new municipal building opened on March 23, 2023 (Figure 32). As part of the climate and environmental project, 80 percent of the furniture in the municipal building and all structural elements are reused (Sørland and Klungerbo, 2021). The bearing structure had to be reinforced with 80 steel core piles to support the new roof level (Blakstad, 2024). At the initial phase of the project, a BIM manual was developed. The purpose of the manual was to establish a foundation for the BIM model to be used in the project (Bærum Kommune, 2019). All glass roofs and windows have been replaced to ensure a better U-value, and the previously open area between the buildings has been transformed into a new glass atrium (Ledsten, 2024). The main initiatives are increasing capacity and improving space utilisation, as well as new walkways to connect employees and communal areas. The building has achieved "BREEAM Outstanding" certification which is the highest possible certification level, as shown in Figure 7.

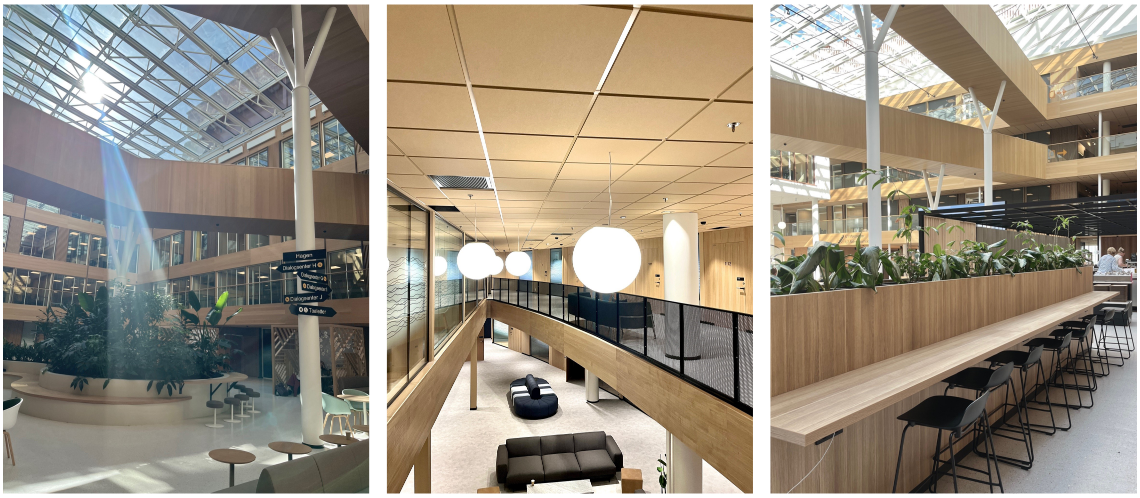

Figure 31: Bærum Kommunegård

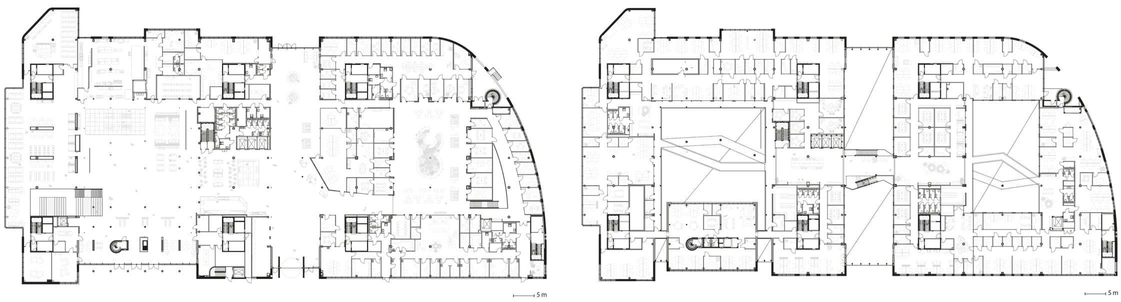

Figure 32: Bærum Kommunegård drawings

Case Study 3

Adress: Dr. Hansteins gate 13, 3044 Drammen
Owner: Storebrand Eiendomsfond Norge KS (SEN KS)
Project Description: Commercial Building
Stage: Finished
Date visited: 20.12.24, 10.04.24

Spor X (Figure 33), designed by the architectural firm DARK, and in collaboration with Vestaksen Eiendom, aimed to explore new construction methods and honour the history of Drammen as a timber city (DarkArkitekter, 2020). The project employs a distinct construction type compared to the other two and is constructed without steel and concrete in the load-bearing structure from ground level and up. Above the basement level, the structure consists of beams and columns made of glued laminated timber, in addition to two elevator and stair cores made of cross-laminated timber (CLT), reinforced with glued columns at the corners. The building comprises 2500 m3 of mass timber produced by Splitkon AS in Åmot, Modum (Splitkon, n.d). The project achieved a BREEAM Outstanding reward (Figure 7) in 2023 for their materials choices (Grønn Byggallianse, 2023a).

Figure 33: Spor X, Dr. Hansteins gate 13, 3044 Drammen

4.3 Analysis Techniques

This Chapter outlines the methodology for analysing the collected data. The analysis will be conducted objectively and the results will be presented in Chapter 5. Subsequently, in Chapter 6, a more subjective interpretation of the findings will be provided. Emphasis has been placed on analysing the data in relation to the research questions of the thesis. For the quantitative data collection, a straightforward comparative method has already been established. For the qualitative material, the approach involves simplifying the information into smaller parts, to understand it from a holistic perspective.

4.3.1 Examination of the Situational Analysis

The responses from the situational analysis were systematically recorded in an Excel document, emphasising the principal insights from each dialogue. Each interaction yielded three takeaways, depending on the conversation's progression. The insights were then consolidated, with one predominant takeaway per discussion being chosen to inform the topic of the thesis. The responses are presented in chapter 5. Due to none of the conversations being recorded, transcription was solely based on notes taken during the interviews. It was crucial for the analysis that transcription occurred immediately after the conversations to ensure no details were overlooked. In hindsight, recording the conversations would have been preferable, as they proved to offer significant insights.

4.3.2 Examination of the Literature Search

The examination is detailed in chapter 3.1.1.

4.3.3 Examination of the Questionnaire

The questionnaire, serving as the quantitative material for this thesis, was used for data comparison through statistical analyses. It was administered over a period of approximately 50 days to guarantee a sufficient number of respondents. After all data had been gathered, each question was transformed into suitable graphs to optimally presenting the data.

4.3.4 Examination of the Semi-Structured Interviews

The semi-structured interviews were analysed using a thematic analysis inspired by (Braun and Clarke (2021)). They can be seen in Figure 34, and are explained below the Figure.

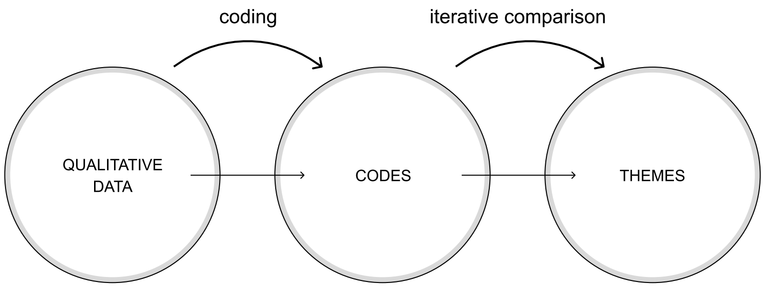

Figure 34: Examination of the Semi-structured Interviews (Braun and Clarke, 2021).

1. **Transcribing**
   The analysis began with transcribing the interviews immediately after each one. This approach also facilitated recording any emergent thoughts during the interview that were not initially documented.

2. **Organise systematically**
   Additionally, the transcription was systematised in Excel to establish an efficient organisational structure. The document was coded to enable the extraction of selected interviews based on background, date, and organisational affiliation. This was done to facilitate easier retrieval of specific quotes and points from the various interviews in the discussion chapter.

3. **Summarise**
   A summary and "key takeaways" were written to ensure that the most important points from each interview were readily available for inclusion in the forthcoming conclusion and discussion chapters.

4. **Coding**
   Subsequently, the interviews were coded based on their content. The main objective of this coding was to systematically organise the text using keywords such as sustainability,

digitalisation, regulation, and experience. This method facilitates more effective linking of the information to the pertinent research questions.

5. **Connect with research questions**
   The codes were filtered according to their alignment with specific research questions. This approach streamlined the subsequent linking process, ensuring direct alignment with the relevant thematic areas.

4.3.5 Examination of Case Studies

The case studies were coded using the same process as the interviews, with emphasis also placed on observations and internet searches for additional information. The studies involved site visits and discussions with individuals directly involved in project execution. The insights gleaned from the questionnaire and interviews rendered the discussions surrounding the case studies especially relevant, as they addressed the challenges previously identified in the research methods.

5 Results

This chapter presents the project results. The results are divided based on the methodology employed. For the semi-structured interviews, each research question is linked to its relevant interview question mentioned in Chapter 5.4. Results are presented in the following order:

5.1) Situational Analysis

5.2) Questionnaire

5.3) Case Studies

5.4) Semi-Structured interviews

The three methodologies "Situational analysis", "Questionnaires", and "Case studies" established the foundational basis for the questions posed in the final interviews. This framework facilitated the implementation of a semi-structured approach, enabling more straightforward follow-up questioning informed by the data gathered through the prior methods. Additionally, the formulation of these questions was refined to correspond with insights from the initial phases, thereby deepening the analytical exploration of the specific areas under study. This development and implementation are shown in Figure 35.

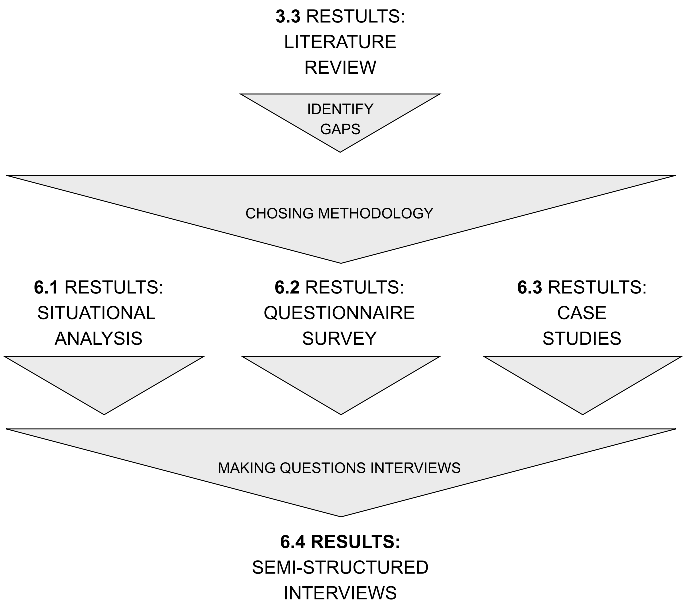

Figure 35: Analytical approach of implementation.

5.1 Situational Analysis

Table 10 identifies three critical terms that emerged from the situational analysis, which subsequently established the foundation for the research questions discussed in Chapter 1.2. The Table presents these essential findings and correlates them with the industry positions of the respondents. The three terms that emerged from the situational analysis were **Communication**, **Sustainability** and **Digitalisation**.

Table 10: Situational analysis.

Person	**Industry Position**	**Key Takeaways**
01	Advisor (1)	Today's construction industry lacks services for comprehensive status overviews and multi-directional communication.
02	Advisor (2)	There is a lack of services for comprehensive and multi-directional communication in today's construction industry, and with digital twins, the geometric accuracy of BIM must be precise to provide value.
03	Advisor (3)	It's challenging to restrain architects, who are always brimming with new ideas. Sometimes, they are told: "We can't do anything about this; it's already been cast."
04	Contractor	The construction industry lags in digitalisation and remains largely characterised by silos across disciplines, IT systems, stakeholders, and national borders.
05	Supply Chain	Project managers need to make sustainable decisions easily. The issue today is that many contractors lack control.
06	Supply Chain (2)	In the planning/design/tender phase, every small cost item of a few thousand kroner is a potential cut, but in the operational phase, unforeseen expenses of several hundred thousand kroner are often not scrutinised as closely.
07	Client	Our development strategy emphasises technology and sustainability as key priorities. Technology and data can optimise the entire value chain.
08	Architect	Early Phase vs Operations: often, the focus is solely on one's own segment of the project, aiming for the lowest cost, which frequently impacts other parts of the project. Should there be a supervisory level overseeing all parts of a construction project?
09	Architect (Start-up)	There is no universally established method for calculating the Life Cycle Assessment (LCA) for reuse materials. What new tools and methods do architects need to work efficiently and effectively with reuse materials?
10	Architect (Start-up)	It is crucial to have actors who facilitate a reuse market, for example, through digital platforms for buying and selling.
11	Sustainability advisor	We depend on the entire value chain and good collaboration to achieve circular construction projects. Mapping is the most crucial aspect. There's significant potential for digital development in this field.
12	Professor, construction/BIM	Standardisation (and automation) is a prerequisite for digitalisation. We need robust platforms for data sharing. Environmental Product Declarations (EPDs) are often in PDF format today. There's talk of making them machine-readable.

5.2 Questionnaire

A total of 59 respondents participated in the questionnaire. The relevant results will be presented in sections as described in Chapter 4.2.2. To check response quality, mandatory question 12 was included: "*If you are paying attention to the questionnaire, please choose option 4 on the linear scale.*". The question received two responses that did not select answer option "*4*". The remaining answers from these two respondents were deleted from the data collection before the results were exported. The remaining 57 respondents selected "*4*" on the linear scale, making their responses relevant to the thesis. The answers are presented according to the question type. A varied selection of charts and graphs has been chosen for linear scale and single/multiple choice, and free-format responses will be summarised in text. The complete dataset, including related questions and their response options for the questionnaire, can be found in Appendix B.

Background: Section 1-8

The respondent's age shown in Figure 36 varied significantly, ranging from 23 to 62 years. This diversity is important for the thesis, as differing levels of seniority and years of experience ensure comprehensive coverage. The gender distribution of the respondents as seen in Figure 37 is 35 men (61.5%) and 22 women (38.5%).

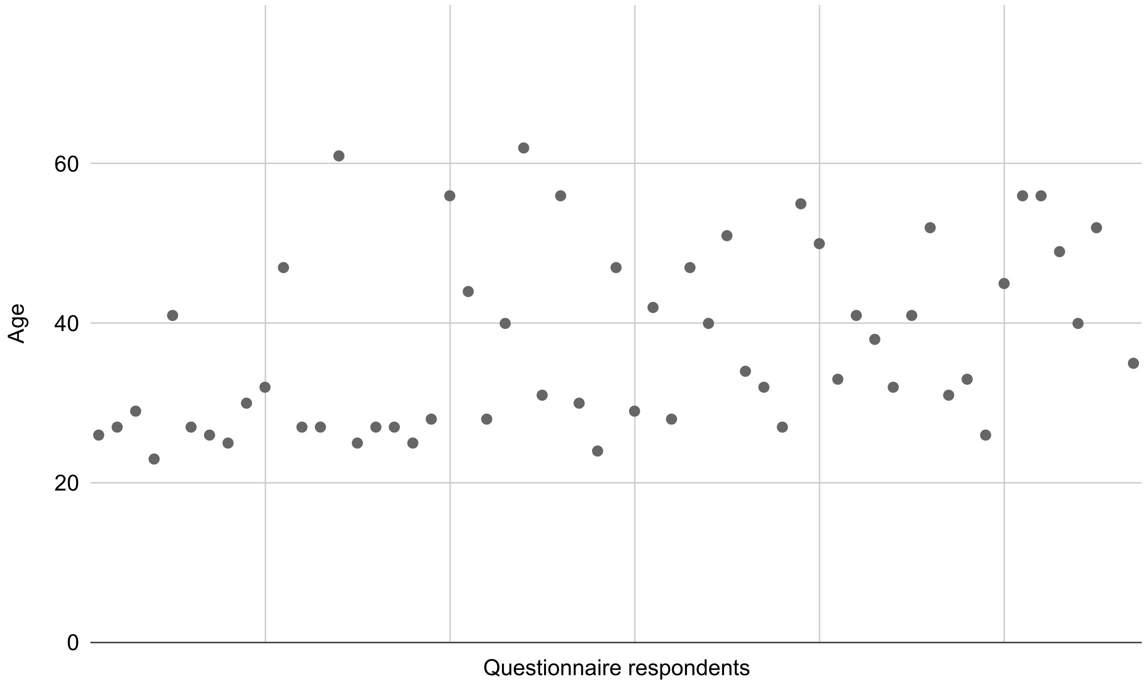

Figure 36: Age distribution of the 57 respondents.

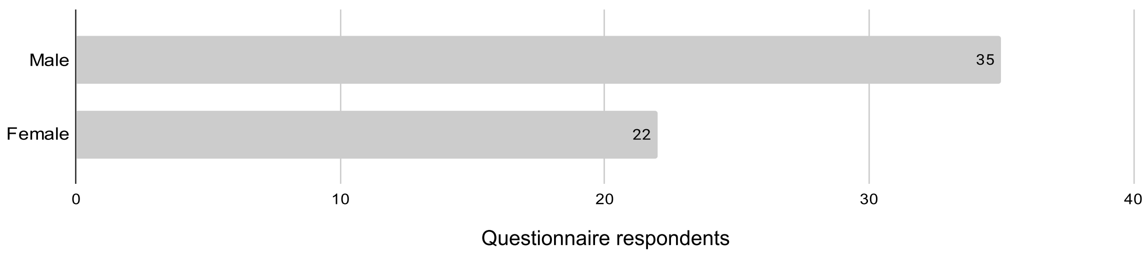

Figure 37: Gender distribution of the 57 respondents.

In Figure 38, we observe that all of the 57 respondents work in Norway. Because of this result, all of the respondents were asked to answer the next follow-up question about their specific location in Norway.

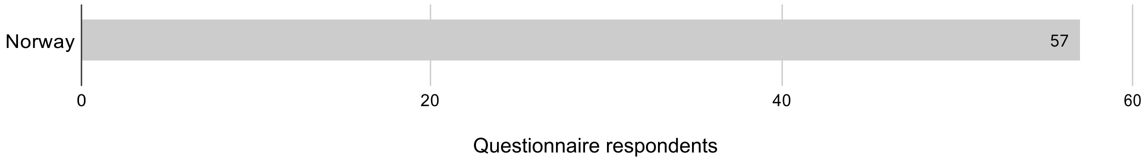

Figure 38: Country of current employment.

From the bar chart in Figure 39, 30 of the respondents worked in *Oslo*, which was the clear majority. This was followed by *Trøndelag*, with *Bærum* and *Innlandet* next in line. The respondents also came from *Buskerud*, *Akershus*, and *Nordland*. This indicates a good geographical distribution.

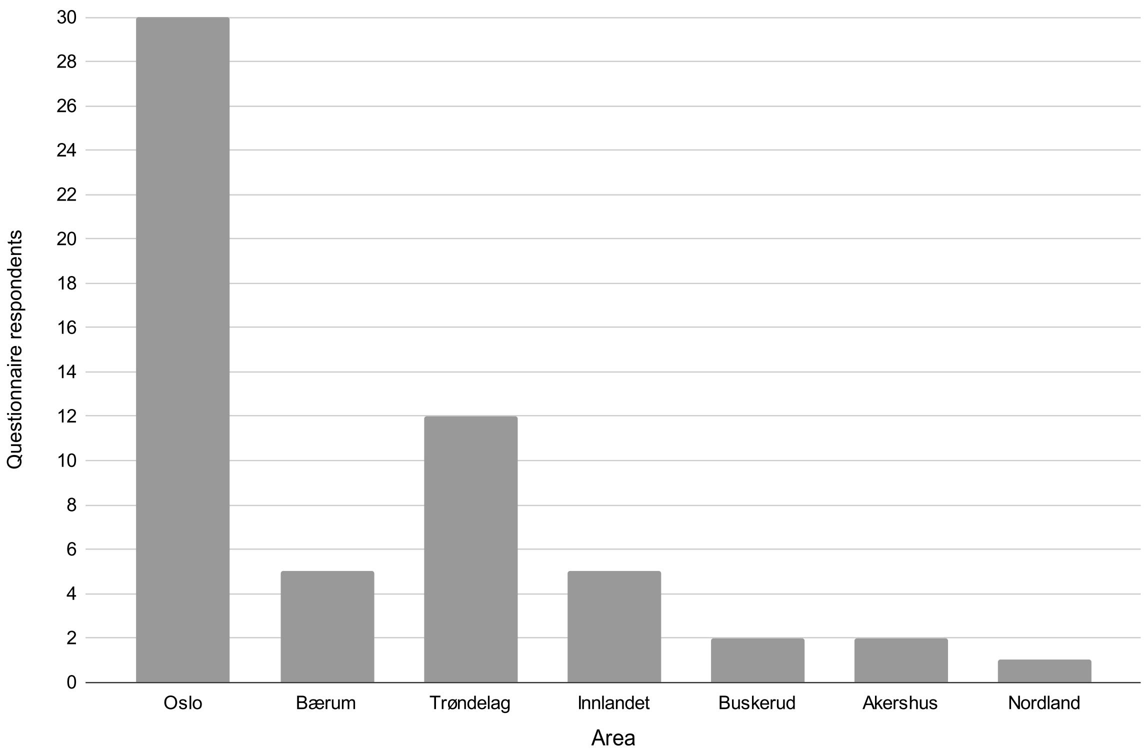

Figure 39: Area of Employment in Norway based on counties.

The respondent's roles are shown in Figure 40. 4 are from the *private sector client* category, 4 from *public sector client* and 13 from *architecture/design*. On the contractor side, 10 respondents are from the *main contractor* category, 3 from the *sub-contractor* category, 3 from *construction advisory*, 7 from *sustainability advisory*, and 8 advisors from *other fields*. The respondents were also from a *start-up* company (one respondent), 4 from *logistics*, 2 from *finance*, 2 from *supply*, 3 from *waste management*, 2 from *research*, and 6 from *other categories*. For the respondents who selected *other*, they were directed to a text field. Their roles included *area planner*, *waste supplier*, *regulatory planner*, *senior advisor in finance*, and *energy advisors*.

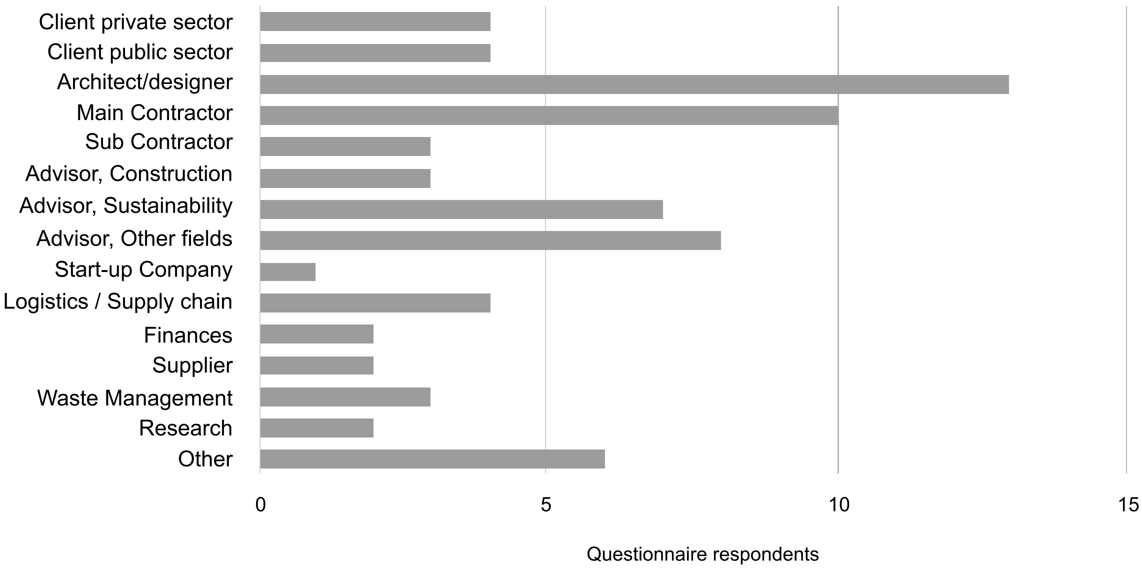

Figure 40: Respondents role in a planning process.

Earlier Projects and Motivation: Section 9-13

Furthermore, the respondents were asked about the type of building in which they were most involved. The results shown on the left side of 41 indicated that 47.4% had been most involved with buildings with fewer than five floors, while 26.3% had worked on buildings with more than five floors. The survey also provided an option to select *others*, which led to a text box. The responses in the text box indicated that the respondents were also engaged in *area development*, *urban planning*, *both*, and *apartment complexes*. Among the respondents, 61.4% have worked with reuse before, while the remaining 38.6% have not, as seen in the pie chart (right) in Figure 41.

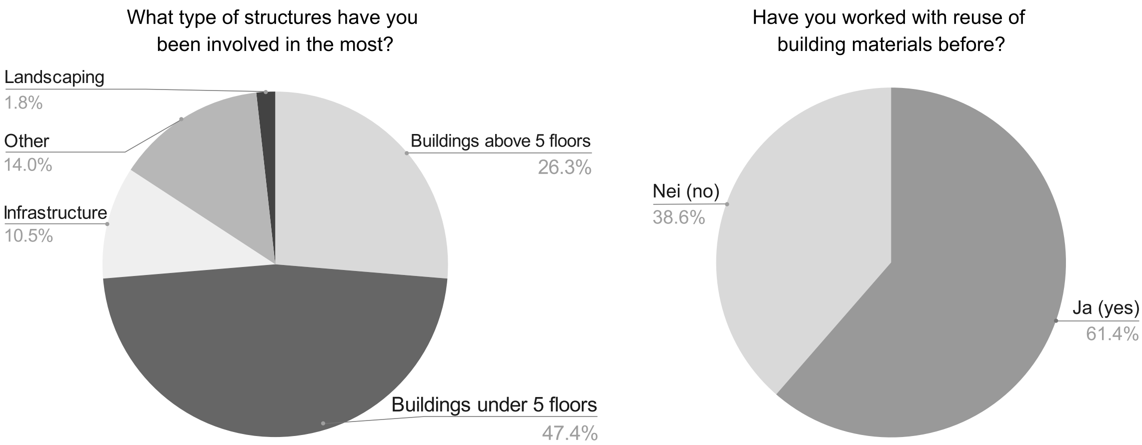

Figure 41: The main building types that the respondents have worked on (left) and whether they have been working with reuse or not (right).

For the multiple-choice question: *If yes, what has been you/your company's motivation to do so?* which appeared if the respondent answered *yes* to the previous question, they could select relevant motivation factors for a reuse project (Figure 42). The most common response was *Desire to be sustainable* with 24 clicks (63.2%). *Social Responsibility* and *Order from external* were next, with 19 (50%) and 17 (44.7%) clicks, respectively. *BREEAM Certification* (13 clicks, 34.2%) and *Positive reputation* (11 clicks, 28.9%) followed. The least popular options were *Regulations & demands*

(9 clicks, 23.7%), *Financial benefits* (6 clicks, 15.8%), and *Higher rental income* (2 clicks, 5.3%). *Others* received 8 clicks (21.1%). Respondents who selected this indicated that some were assigned the task, while others were working towards knowledge building. One respondent wrote, "The building in the project was planned for demolition, but then the economic situation in Norway changed (in the last two years), and the developer scaled down the project, preferring instead to transform and build on the existing building." The final respondent who chose *Others* stated that their motivation was research.

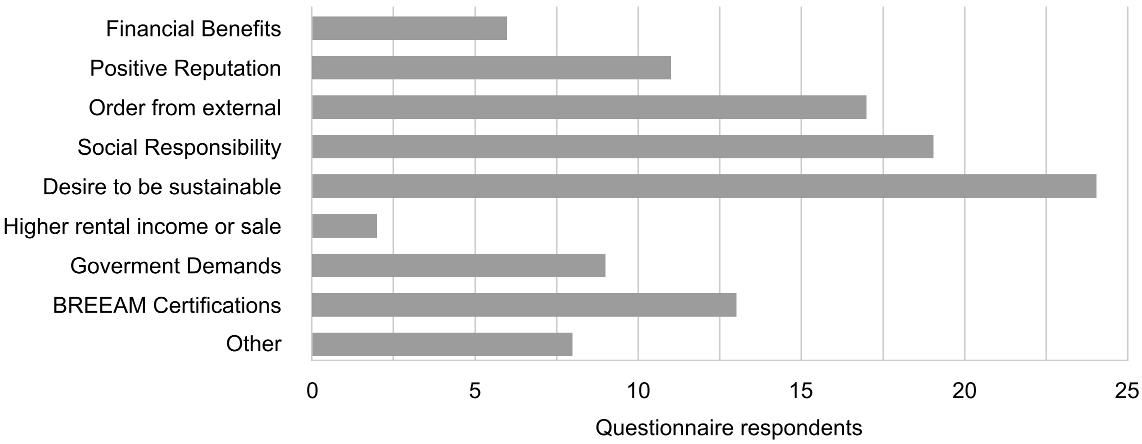

Figure 42: The respondent's motivation for reuse, multiple choice question.

Role and Main Challenges: Section 14-17

For the topic of key challenges with the question: *What are your thoughts on main barrier for a successful reuse project?* (Figure 43), as a multiple-choice question, 78.9% (45 respondents) cited *Costs* as a major issue. *Regulations* (23 responses, 40.4%), *Logistics* (24 responses, 42.%), *Attitude* in the industry (24 responses, 42.1%), *Knowledge* (23 responses, 40.4%), and *Time* (22 responses, 38.6%) were also commonly viewed as significant problems. Additionally, *Interest/Motivation* received 12 responses (21.1%), *Benefits* received 14 responses (24.6%), *Documentation* received 16 responses (28.1%), and *Communication* received 12 responses (21.1%).

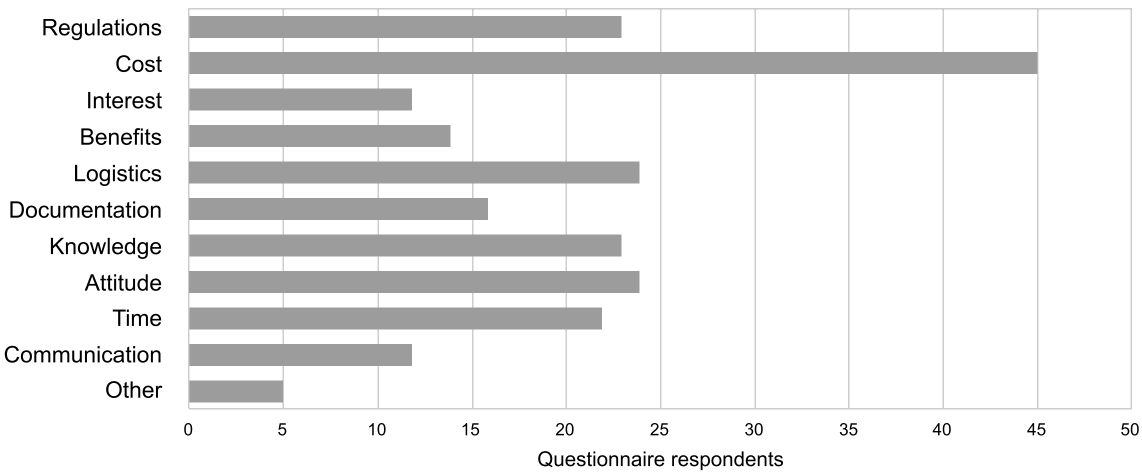

Figure 43: Main challenges of a reuse project.

In addition to these areas, an additional text field was provided for further thoughts on the main challenges. The points raised were “lack of data standardisation”, “liability declaration for reused building materials”, “uncertainty about the quality of materials” and “need for new digital tools”.

In response to the question: *To what degree do you see reuse of materials as feasible in today’s building industry?*(Figure 44), 26 respondents chose option “3”, which is the midpoint on the scale. These 26 respondents make up 45.6% of the sample. Option “2” was selected by 13 respondents, accounting for 22.8%. Additionally, option “4” was chosen by 10 respondents (17.5%), option “5” by 6 respondents (10.5%), and lastly, option “1” was selected by the fewest respondents, numbering 2, which corresponds to a percentage of 3.5%.

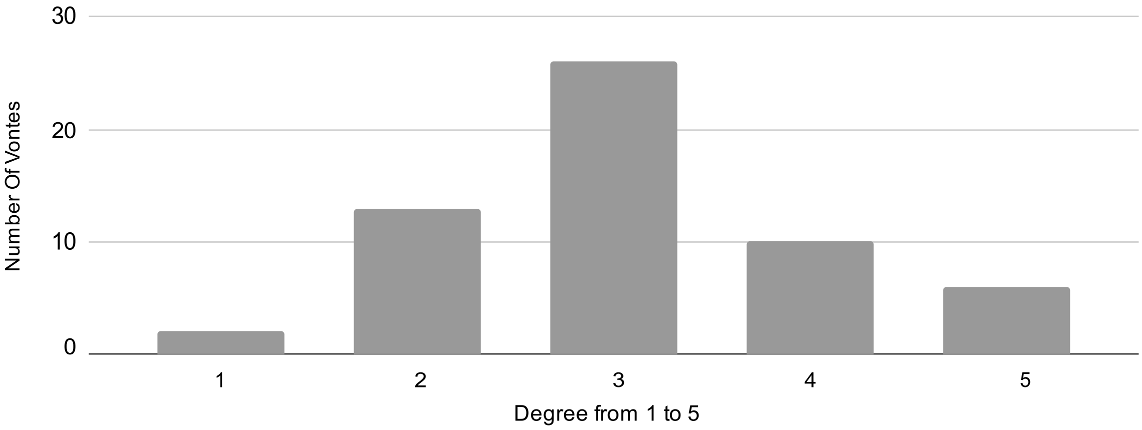

Figure 44: Degree of reuse possible in today’s building industry.

For the question: *With current regulations, to what degree do you see the emissions from new materials as a limiting factor in the planning process of a project?* in Figure 45, the most responses were for option “2”, which was chosen by 20 respondents. Options “3” and “1” were chosen by 15 and 14 respondents, respectively, while option “4” was selected by 7 respondents, and option “5” by just 1 respondent. This means that the three lowest response options (1, 2, and 3) were chosen by 49 respondents, representing a total percentage of 86%.

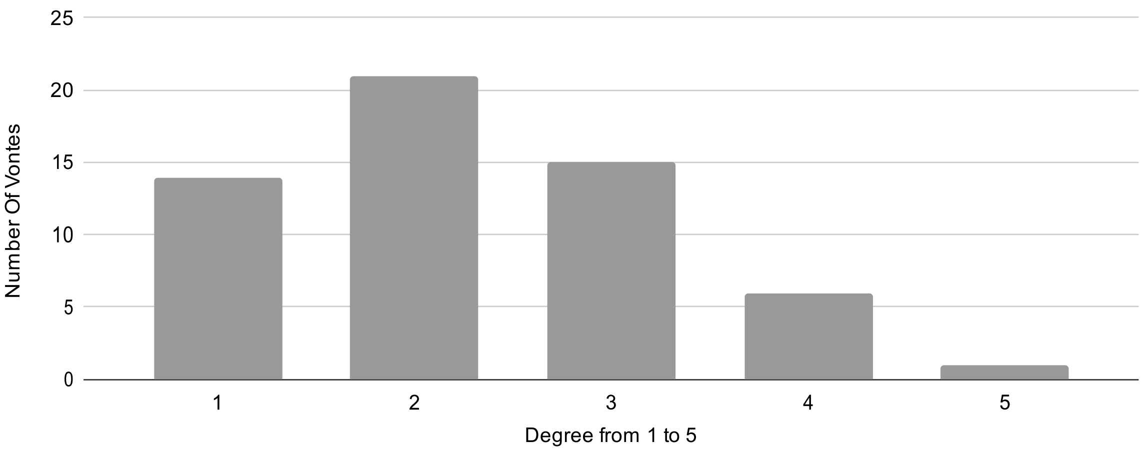

Figure 45: Degree of emissions from new materials as a limiting Factor.

Barriers and Drivers: Section 18-20

Furthermore, the respondents were asked to rank, on a scale from 1 (major barrier) to 5 (major driver), the extent to which different categories act as a barrier or a driver. The categories are shown in Figure 46, and the key shows which colour corresponds to which ranking each category received.

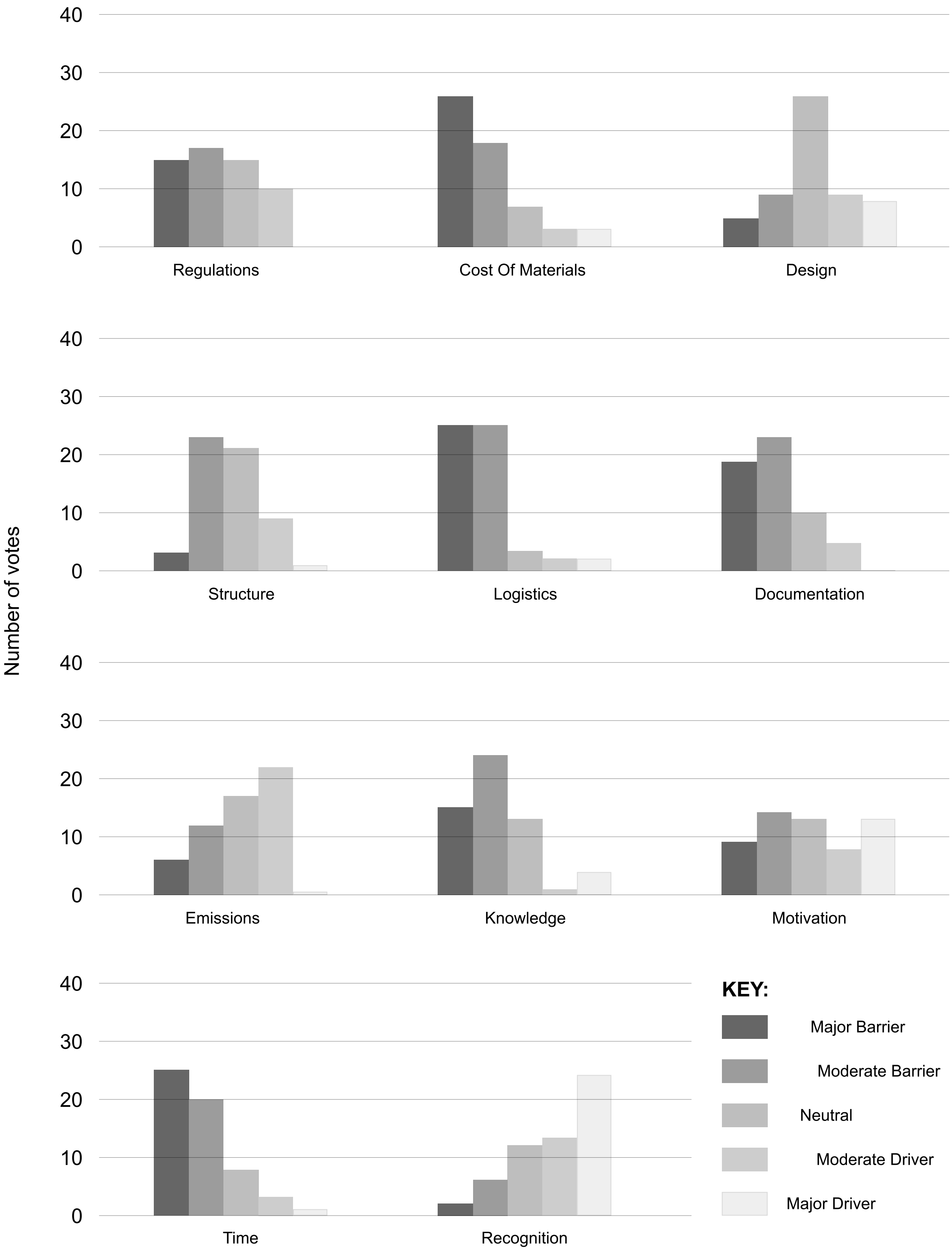

Figure 46: Barriers and drivers in different areas.

Regulations and Digitalisation: Section 20-27

27 respondents chose option “1” for the question: *To what degree do you think that the regulations today are strict enough in relation to requirements for reuse?* as seen in Figure 47. This accounted for 47.4%, a clear majority. Twelve respondents chose option “3”, and 11 respondents chose option “2”. The fewest chose options “4” (5 respondents) and “5” (2 respondents), which together accounted for 12.3%.

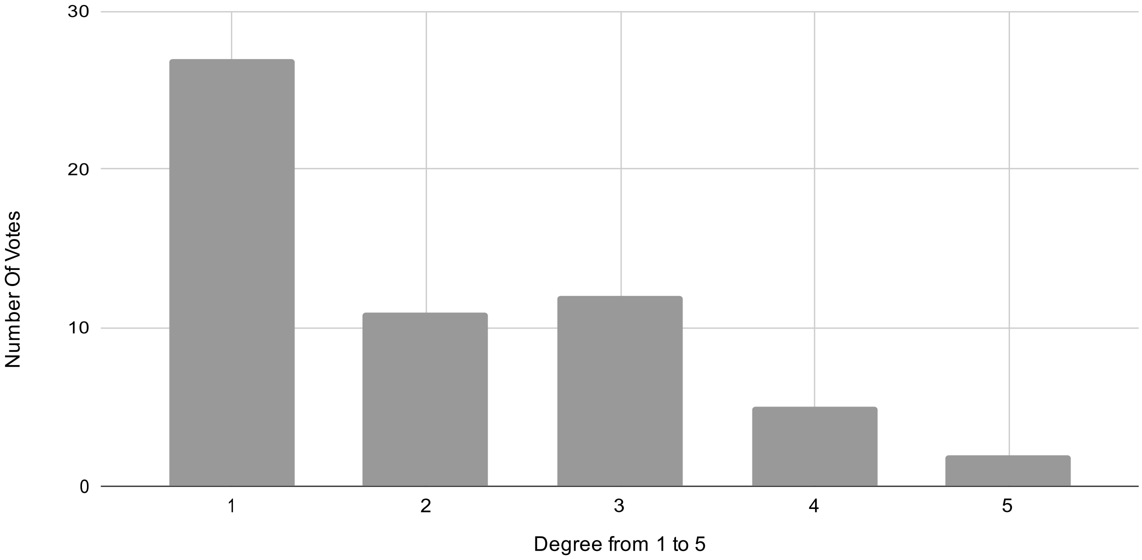

Figure 47: Degree of stricks enough regulations in today’s industry.

Furthermore, the respondents were asked what they assumed a reuse component would cost in relation to a new one (Figure 48). The majority of the respondents (23 individuals) chose the option *higher, up to 150%*. The option *significantly higher, 150% or more* was selected by 9 individuals, while the rest opted for lower amounts such as *equal* (8 individuals, 14%), *lower* (12 individuals, 21.1%), or *unsure* (5 individuals, 8.8%).

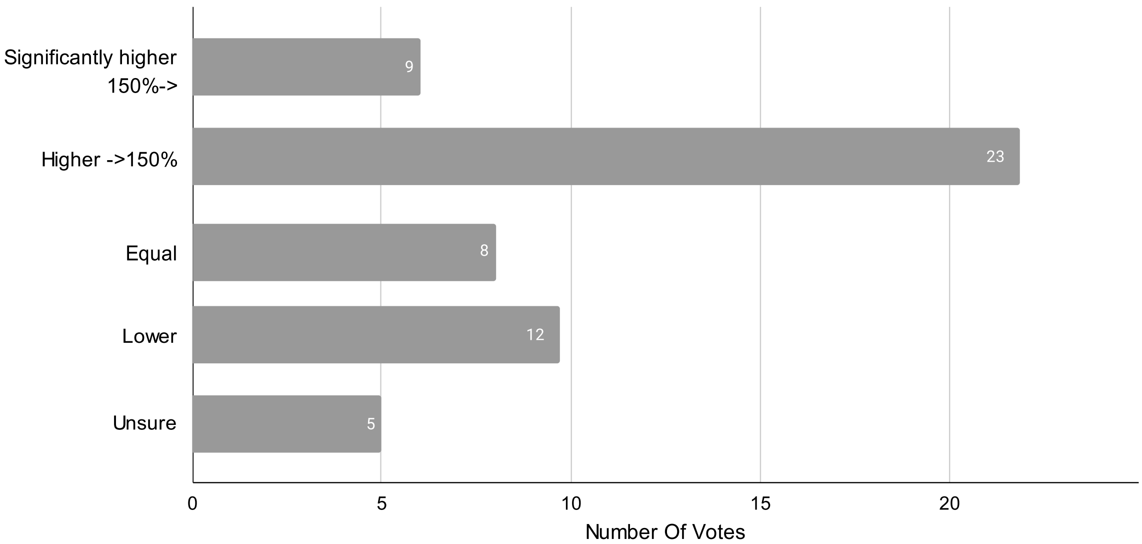

Figure 48: Expected average price of a reused component compared to a new.

For the next question (Figure 49):, *To what extent do you believe digitalisation will impact the* *potential for sustainability in the future?*, 26 respondents (45.6%) selected option "5", which is the highest possible option. This was closely followed by option "4", selected by 22 respondents (38.6%). Seven respondents chose option "3", which accounts for 12.3%, while two selected option "2" (3.5%), and no one chose option "1".

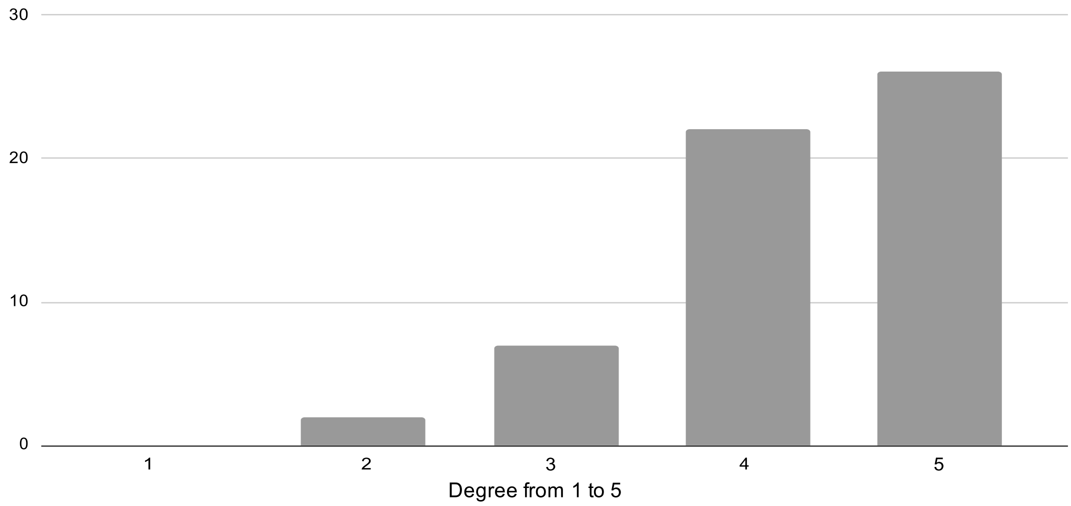

Figure 49: Digitalisation impact and the potential for sustainability in the future.

Figure 50 is divided into two charts, each representing their own question. The left pie chart represents the responses to the question: *Do you think that there is good enough communication across subjects and departments in the industry?*. Here, 91.2% answered *Yes*, which accounts for 52 respondents. The remaining 5 respondents (8.%) answered *No*. The right pie chart in Figure 50 represents the question: *Do you believe that the current regulations are sufficient to support the practice of reuse?*. 39 respondents chose the option *No*, which accounted for 68.4% and is indicated as the lightest section in the figure. Additionally, 17 respondents (29.8%) answered *Both*, and one respondent chose *Yes*.

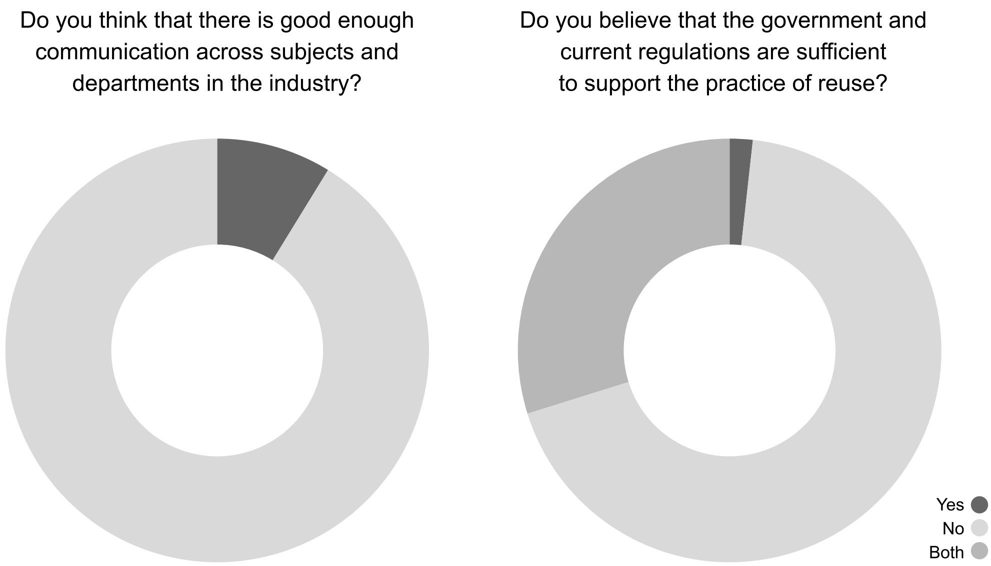

Figure 50: Communication across subjects and departments (left) and Regulations and their sufficiency to support the practice of reuse (right).

For the respondents who answered *No*, they could elaborate on the subsequent question by writing down what they believed needed to be done. The comments that were written were the following:

- *"The state must provide greater incentives for companies and developers to choose environmentally friendly products."*
- *"There should be more focus on logistics and sorting of materials."*
- *"There should be higher requirements for reuse materials and local materials."*
- *"The state must ensure that developers are motivated to invest time and money in this area."*

In conclusion, the respondents were given the opportunity to provide additional thoughts on the topic to ensure that key experiences and opinions were included in the survey. The comments are displayed in Table 11.

Table 11: Final question in questionnaire, thoughts regarding the topic from the respondents.

Person	**Quote:**
Respondent 1	"*I believe attitudes and knowledge are major barriers in normalising the reuse of materials/constructions. I'm not sure about the cost implications, but poor knowledge could lead to the misconception that it is more expensive/time-consuming than it actually is.*"
Respondent 2	"*Reuse needs to make sense. For example, a water closet that must be disassembled, stored, have parts replaced, certified, and reassembled can end up being 5-6 times more expensive than a new one. I don't see the economic benefit in reuse there.*"
Respondent 3	"*Reflection: I believe that the private sector has the capacity, knowledge, and resources to reuse both structural and aesthetic building materials. Unfortunately, it's costly and time-consuming. The construction industry doesn't have a surplus of either. It has to be made lucrative to build sustainably. As soon as it becomes profitable, I believe the industry will change overnight.*"
Respondent 4	"*Good questions in the survey! I think there should be a Finn.no for building materials and reuse.*"
Respondent 5	"*Great survey! There is an important distinction between internal reuse within the same project/property portfolio and external reuse across different actors. I find that the former is reserved for a small elite of resource-rich actors and occurs on a very limited scale, while the latter is still a somewhat visionary idea with enormous potential that could open up access for everyone. We are starting to take reuse mapping seriously, and more hubs and marketplaces are emerging. Now, we need tools that allow the project team to communicate about available materials at an early stage and to use them in a way that is compatible with current digital work practices. This should be done in parallel with additional regulations for transactions and documentation simplifications that can facilitate resale.*"

5.3 Case Studies

The case study (Table 12), results will describe the hypotheses from the previous methods and theory in practice. The outcomes will detail both the positive and negative aspects of the projects.

Table 12: Case studies with address and owner.

No.	Name/Address	Owner
1	Odins Gate 4, Oslo	Oslo Kommune
2	Bærum Kommunegård	Bærum Kommune
3	Spor X, Drammen	SEN KS

Odins Gate 4, Oslo

In case study no.1 (Table 12), the accuracy of the theory from the situational analysis and questionnaire was examined. After discussing with the contractor, architect, and workers on-site, it became evident that time, cost and logistics due to delays were major concerns. Although the project was initially planned as a reuse initiative with numerous measures, various challenges arose once it started. The results in this case study aligned with the theory. Observed from the questionnaire results, in the area of *key challenges in reuse projects* (Figure 43), the case study is a good representation of reality, with 45 respondents selecting *cost*, which had the highest number of votes. *Logistics* had 24 selections, and *time* had 22, placing them high on the list as well.

> *There is a cost-benefit and economic aspect that always makes reuse challenging to implement. It is not prioritised, especially when unpredictable events occur.*
>
> Architect, Case study 1

The hallway tiles were intended for reuse (images left and center, Figure 51), but the process of collecting, cleaning, and relaying them was too costly and time-consuming and therefore it was abandoned. Additionally, the railing (Image right, Figure 51) was supposed to be retained, but new regulations made it non-compliant with current standards. The results from the questionnaire show in question *Do you believe that the government and current regulations are sufficient to support the practice of reuse?* (Figure 50, right chart) that 39 respondents chose *No*, and the results from this case study confirm the theory that new regulations often hinder reuse.

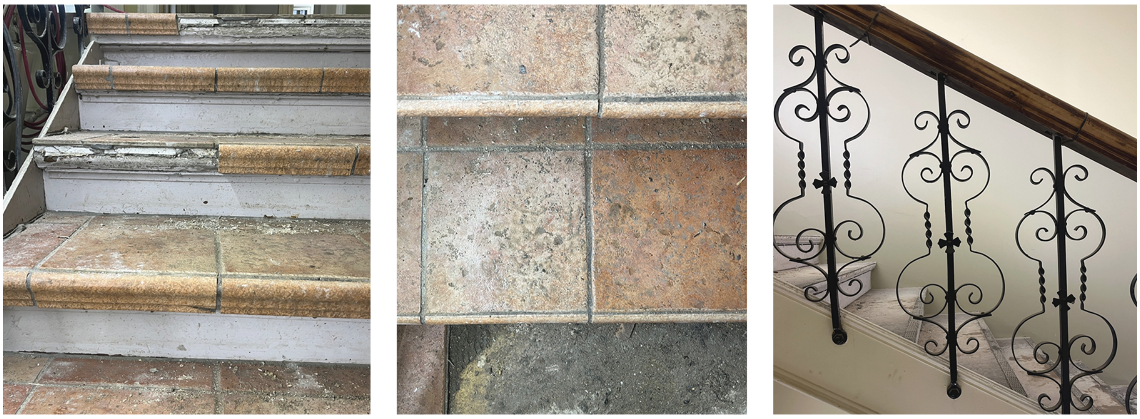

Figure 51: Images of reuse plans that were not implemented due to time and regulatory issues. (Left and center: tiles in the hallway. Right: railing), Odins Gate 4

The house rot mentioned in Chapter 4.2.4 caused reuse initiatives to be not prioritised, and several delays were discovered. In addition, this project was intended for Ukrainian refugees, and there was a desire for rapid completion to accommodate people quickly. This urgency may have influenced several processes. The delays impacted several parts of the project due to logistics, including the availability of excavators. This confirms the theory and the qualitative and quantitative methods that hypothesised logistics on the construction site as a significant issue.

Bærum Kommunegård, Bærum

In case study no.2 (Table 12), from the survey conducted by Sørland and Klungerbo (2021), it emerged that achieving BREEAM Outstanding certification (Ref. Chapter 2.3) and a desire to avoid demolishing any part of the building was high on the agenda. It was also considered profitable in the long term to invest in and bear the costs of renovation, as more people could be accommodated in the building after the renovation. Area of the site and project can be seen in Figure 52. Demolition was ruled out as an option because the load-bearing structure still had a viable lifespan, and retaining it was deemed beneficial for both climate and economic reasons.

> *No private entity would have done this. They would have demolished and rebuilt, as that is more cost-effective. I believe very few people think, "Okay, it will be more expensive, but we'll do it for sustainability reasons."*
>
> Building Owner, Case study 2, quote taken from Sørland and Klungerbo (2021)

Figure 52: Model on site, Bærum Kommunegård

As mentioned in Chapter 4.2.4, a BIM model was created in the initial phase of the project. Given the building's initial conditions, the BIM model and scanning process indicated that the project and reuse plans were feasible. The analysis showed that the floor heights met current regulatory standards, which is often a major challenge in renovation projects. Additionally, many of the building's elements were found to have a considerable lifespan remaining, further supporting the feasibility of the reuse plans.

These conditions made the project appear viable and showcased the potential for success in such initiatives. The project demonstrated that reuse projects can be achievable with the right initial conditions.

Spor X, Drammen

Case study no.3 (Table 12), as mentioned (4.2.4) are built with CLT (Figure 53: left image). The CLT materials were from Åmot and produced by Splitkon, located just 30 minutes away from the construction site. The use of CLT in today's construction industry is still relatively new, meaning that few buildings have stood for an extended period. Cracks were observed in the timber (Figure 53: right image), which could potentially become problematic over time. Timber expands and contracts due to temperature and movement, and the building's design takes this into account.

Figure 53: Spor X structure in CLT (left) and observed cracks in the cross-laminated timber (right)

The adoption of CLT stands as the key rationale behind Spor-X's achievement of the prestigious "BREEAM Outstanding" certification (Figure 7), thereby presenting a crucial argument for the structure's future viability and sustainability credentials. This certification is acknowledged by the building owner as a significant aspect contributing to the building's future prospects and profitability.

> *We observe that our tenants value our BREEAM certification, and the building is a popular rental property. As one of the few projects with cross-laminated timber on all floors, we are extremely proud of the outcome.*
>
> Building Owner, Case study 3

From the interviews for research question 1, interviewee 2 (seen in Chapter 5.4.1) stated that the building owner *holds the purse strings and does not understand why they should lose money on reuse*. We see that this was not the case in this project, as the building owner recognised several advantages of the project in terms of both reputation and rental income.

The questionnaire results indicate that among respondents to the question: *If yes, what has been your/your company's motivation to do so?* (Figure 42), 11 individuals cited *BREEAM certification* as one of their reasons. Furthermore, four respondents also highlighted *higher rental income or sale* as a motivating factor, a trend corroborated by the case of Spor-X. This underscores the perceived value of certification in enhancing the building's market appeal and potential financial returns.

5.4 Semi-Structured Interviews

The interviewees are presented in Figure 54, with details of each interview outlined in Table 8, Chapter 4.2.3. Among the interview subjects, there were three architects (1, 2, 8), three advisors (3, 4, 5, 7), and one client (6). The results are organised with sub-sections systematically addressing each research question. The organisation of the results is important due to the complexities of semi-structured interviews, which have a wide variation in responses from different interviewees. When referencing information and quotes from the interview subjects, they will subsequently be referred to in this chapter by their respective numbers from the figure, alongside their field of work.

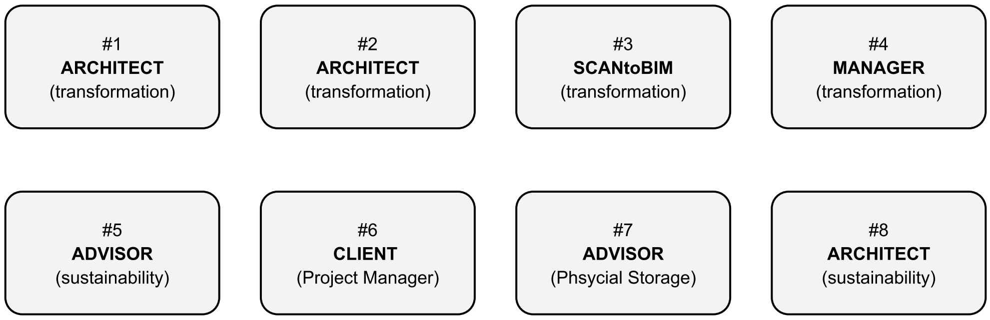

Figure 54: Interviewees for semi-structured interviews.

5.4.1 How do stakeholder roles and interactions influence the effectiveness of material reuse strategies in the construction industry?

Questions asked for this research question were the following (Appendix C):

- How can you influence projects in terms of reuse in your role?
- How do you comply to industry regulations, particularly in relation to BREEAM, TEK17 requirements, FutureBuilt, and other new regulations or recommendations that have emerged? Any other worth mentioning?
- In your opinion, how do stakeholders interact in terms of reuse in the industry?
- How do you think digitalisation can facilitate increased reuse?

After interviewing across disciplines, the building owners, as stakeholders, viewed their position as the most influential. Interview subject 6 believed that they had considerable internal influence within their company and the capability to secure additional funds to promote reuse. It was mentioned that building owners often used internal advisors whose primary goal was to promote reuse. It was emphasised that this was a relatively new practice. One of the building owners believed that their position had to take responsibility for proper development, and they always tried to directly engage in each subjective project to influence it. The interview subject who expressed this view was from the municipal sector. Interview Subject 1 believed that architects in the early phases had a lot of influence, but ultimately, it was the building owner who made decisions. Therefore, according to them, it was the architect who had to facilitate this in the best possible way so that the building owner could make such choices more easily.

Ultimately, it is the building owner who holds the purse strings and does not understand why they should lose money on reuse.

- Interview Subject 2

The advisors who were interviewed had different approaches to the issue. Interviewee 5, who primarily advises on sustainability, stated that they had the potential to influence, but there was often a time pressure that was hard to ignore. This resulted in other matters being prioritised. They also mentioned that there was good cooperation on this matter between the building owners and advisors, but the contractor often came in too late to be able to participate in these influences. Interview Subject 4 mentioned that as an operations manager, they had significant influence. This was largely because their and other typical advisory roles often involved close dialogue with suppliers and purchasers. This ensured that they could arrange for local materials and establish standards for the projects. They also emphasised that it was not just the choice of materials that was important but also the placement of buildings in relation to transport hubs and that it was crucial these aspects were well communicated across disciplines. According to them, this was important because the project's participants were responsible for its construction and operational phases. Decisions like the proximity to public transport impact the environment after the building is completed, encouraging users to choose public transport and reduce their environmental footprint. It was argued that making it easy for building users to choose eco-friendly options is a key responsibility. However, according to them, such decisions are highly site-specific and not always feasible for all projects.

Customers have higher expectations than before, which naturally leads to spending more time on the mapping part of the project, carefully discussed with the building owner. This forces discussions across stakeholders to achieve the best possible project to satisfy the customer.

- Interview Subject 4

The advisors mentioned that there was a significant difference among building owners regarding the desire to prioritise reuse. They believed this was because building owners vary greatly in size, and the larger and well-established ones often have an advantage in this area. Some building owners were also keen to be known in the industry as leaders and are naturally more inclined towards this area. Interview Subject 5, who primarily works with the company as a whole, emphasised that influence was not limited to individual projects but extends to the entire company. It was noted that reporting from the entire ESG (Environmental, Social, and Governance) segment of the company initiated compliance with new regulations, such as those set forth by the EU. This, in turn, would also be reflected in specific projects. The individual mentioned that they are currently in the process of developing sustainability coordinators within the company to define this role more clearly. Emphasis was placed on the importance of ensuring that all company employees knew about sustainability and how to achieve it in the most effective way. As an example, the individual cited that internally, their company organises "sustainability weeks", which served as an initiative to educate each other on various topics related to the theme.

As an organisation, we can influence by ensuring that the entire organisation prioritises reuse reporting such as CSRD reporting, environment and climate, EU, and ESG *regulations. This will, in turn, impact our projects. We have also established a sustainability group that focuses specifically on regulations in the industry. Therefore, it is crucial to see the bigger picture.*

- Interview Subject 5

Interviewee 7 believed that a positive sharing culture was emerging across all disciplines. They referred to collaborative platforms involving 40 different companies from various fields and noted that the entire value chain was increasingly collaborating on funding reuse projects. The informant also mentioned that particularly from the “client” side, no natural crossover points for collaboration had been evident before, but that this was now beginning to change.

More companies are now willingly sharing their experiences, perhaps as a result of larger knowledge-sharing platforms. We see an increased sharing culture among all disciplines that wish to work with reuse.

- Interview Subject 7

5.4.2 What early-phase mapping solutions have been developed to date, and how do these function in practice?

Questions asked for this research question were the following (Appendix C):

- What methods do you/your company use in your projects to achieve successful reuse projects?
- Any digital software or external mapping solutions?
- Can you please explain how these methods play out in practice in a “typical” construction project?
- Does your organisation focus on digitalisation in projects? If yes, how?

Interview subject 4 said that as advisors, they did not have any absolute tools that was mandatory to use in the company, but rather provide advice on individual projects. Within the projects where sustainability coordinators were used, a report was typically produced to show the degree of reuse. This reporting is a relatively new standard, and reference was made to the new regulations explained in Chapter 2.3. These regulations was the groundwork for the increasing desire for such a process, according to them. There was no standard process for how this reporting works, but they mentioned that various standards had been tested internally within the company.

We have 71 offices, from small to large. The process is the same, but these days we notice that we spend more time on mapping. We enter into a specification of requirements that we discuss with the lessor. We are making more demands than before, but we have no standard for the mapping phase.

- Interview Subject 4

From the interviews with the building owners, several digital tools were mentioned that assist with early-stage mapping. Specifically, platforms such as “Loopfront” were referenced, in addition to the competition DIPLOM, which is discussed in Chapter 2.6.2. The challenge associated with the platform was described as only a few other actors having registered their reusable materials on the platform, coupled with employees being minimally trained on the programs. One of the building owners mentioned that in their area, there was no physical storage facility, and they explained this by stating that it represents a significant investment and a “battle for square meters” that competed with many other important projects. This informant expressed a desire for the establishment of another actor in the industry that could focus on physical storage and that this necessarily should not be a responsibility that the building owners could or should take on.

> *As building owners, we have several advisors who use or refer to digital tools for which we have licenses. Some of the surrounding buildings have also registered some components in the same tools, but there is a challenge and barrier to more fluid data flow across certain actors. We need a system change!*
>
> - Interview Subject 6

From the developer’s side, it was also mentioned that they are currently attempting to digitalise all existing buildings so that the data is ready for further use and modifications. Interviewee 6 manages 33 school buildings that are in the process of being digitalised. It was mentioned that it was important for them to improve the quality of the data in the system so that they could use it in upcoming development work. This digitalisation process is often carried out externally via laser scanning, a process described by Interviewee 3, who advises on and conducts such procedures:

> *We commence by sourcing all previously prepared foundational materials, which include drawings, spatial measurements, and calculations. Then, a pricing process is undertaken. Following this, the work is executed, and the delivery includes data in the form of point clouds and benchmarks that can be used in multiple phases. We are usually also requested to generate BIM models from 3D scans, for which we utilise historical 2D drawings as supplementary resources and provide web-based viewing solutions.*
>
> - Interview Subject 3

Informant 7 states that at their physical storage station, they had a logistics system, established through collaboration with the industry, that allows private individuals, clients, and contractors to buy reused materials. The project was approximately one year old and operates in such a way that one could choose to pay for an area in the building to store their materials or buy/sell to the facility. The informant also mentioned that they were in contact with storage stations across the country and engaged in extensive digital knowledge sharing.

> *Physical storage is becoming more common in various areas of Norway and is developing rapidly.*
>
> - Interview Subject 7

5.4.3 How can we facilitate increased reuse in the industry during the early stages of the project?

Questions asked for this research question were the following (Appendix C):

- From your perspective in the industry, what do you think is our biggest challenge when it comes to reuse in construction projects?
- From your perspective, how can we facilitate for increased reuse in the industry?
- What do you believe needs to be done with regulations to facilitate reuse?
- Where do you think we will be in 10 years in this area?

Informant 4 mentioned the need to build flexibly to facilitate reuse in the future. They pointed out that the pandemic has brought a conscious focus to this issue, highlighting that we do not know what "the construction site of the future" will look like, and therefore, we must be adaptable. Informant 5, who is also on the advisory side, believes that processes like this will need to be much more systematically organised than they are currently. They argued that there should be stricter regulations from the government that make things clearer and easier. There was a clear consensus among all informants that the state must contribute to the issue. This point was raised by architects, advisors, and building owners alike.

> *We must build flexibly for the future. Many changes are occurring, and there are always new ways of working. We must be prepared and ready for changes.*
>
> - Interview Subject 4

Several informants were also concerned that current conditions are not conducive to facilitating reuse most effectively. The informants had differing views on how this could be better supported, but many mentioned that the state must contribute more, as it has done in other industries before. Economic incentives and well-organised infrastructure was believed by informant 2 to be significant drivers for enhancing the opportunities for reuse.

> *There must be initiatives from the state to facilitate reuse. The electric car is a good example of this. The electric car is subsidised, the infrastructure is prepared for it, and therefore, it pays off.*
>
> - Interview Subject 2

Several informants voiced concerns regarding current regulations and emphasised the necessity of modifying them to facilitate reuse. Today, there are generally stricter requirements than when the potential buildings to be demolished were constructed. As a result, many of the materials from the donor buildings cannot be reused because they do not comply with today's specification standards. In addition to regulations, digitalisation was identified as a significant area of focus, both because several questions were directed towards this and because the informants were clearly engaged with the topic. Some informants, particularly the building owners, were aware of various solutions they wished to implement. Generally, digitalisation, in the form of laser scanning, was highlighted by both advisors and architects as a crucial area that needed to be utilised more for efficient and beneficial storage in the future.

> *We need to make greater use of digital tools and employ laser scanning as an aid. How about having a catalogue of reusable materials available at all times and some kind of alert system? The problem is that there is no overview available for us architects today.*
>
> \- Interview Subject 1

Informant 7 emphasised that the industry needs clearer wording around regulations and technical requirements. They mentioned that there must be documentation requirements that are easier to navigate and that there is a significant need for greater standardisation. During the conversation, there was also extensive discussion about the need for digital alignment, with examples given of different internal digital platforms used for example "Loopfront" (ref. 18). The informant replied that there is a need for a better overview of the total offering but highlighted that this alignment process is already well-discussed and somewhat underway. The informant also emphasised that the market today is not equipped to scale as quickly as desired, and much of this is related to development and regulatory requirements within the industry.

6 Discussion

This chapter discusses the results emerging from the various methods used in Chapter 5. The chapter is divided into the three research questions, and the results will be discussed in their entirety to address the research problem in the best possible way.

6.1 How do stakeholder roles and interactions influence the effectiveness of material reuse strategies in the construction industry?

6.1.1 Communication

Early on, the situation analysis revealed that communication was an important area of focus. This was again confirmed when the questionnaire showed that a clear majority (91.2%) believed there was insufficient communication across all disciplines and departments in the industry (shown in Figure 50, left chart). As the questionnaire focused on a larger number of individuals than the situation analysis, it also captured a larger part of the industry. Enhanced communication within the industry is necessary, as highlighted by Interviewee 4's emphasis on multi-directional communication challenges and supported by the questionnaire findings. The importance of collaboration across disciplines was underscored by Interviewee 7's remarks on the sharing culture within the industry and supported by questionnaire responses indicating a desire for better cooperation among stakeholders. There is a growing trend towards a sharing culture, with a main focus on platforms serving as knowledge hubs, as described by interview subject 7. This shift can significantly influence communication dynamics, as building relationships and connections can make dialogue easier. The findings suggest that the industry remains fragmented, with many individuals working in isolation. Therefore, a culture of sharing can enhance knowledge exchange, relationships and communication across different disciplines.

The findings can be interpreted as all disciplines having a common conception of the issue. As the industry is disconnected, it can be interpreted positively as all unity sharing the same opinion. However, it was unclear how this communication could be prepared. Effective communication among stakeholders is crucial for the successful implementation of material reuse strategies. The interviews revealed that building owners, architects, advisors, and clients all play significant roles in influencing decisions related to material reuse. Building owners, in particular, were identified as having considerable influence, as they control the budget and can secure additional funds to promote reuse. In addition, internal advisors within building owner organisations are increasingly dedicated to promoting reuse, which shows a positive shift towards sustainability. Architects, although influential in the early phases of a project, ultimately rely on building owners to make decisions regarding material reuse. This underscores the importance of effective communication between architects and building owners to ensure that reuse options are presented early in the process. Additionally, it is important to be aware of other planned local demolition projects, as they might contain materials available for reuse. Identifying these opportunities can help maximise the use of reclaimed materials in new construction.

The case study of Odins Gate 4 highlighted the importance of communication in project success. The study exemplifies how effective communication practices can be implemented, particularly in smaller projects with a limited number of stakeholders and employees. This environment facilitated dialogue between the architect and the contractor, which might not be common in larger scale projects. Such communication was crucial, as it ensured that the architect was informed of any changes and logistical challenges. This early notification enabled redesigns and replanning, which benefited the project's focus on reuse. From the case study of Spor X, it was evident that the property owner's wish to achieve BREEAM Outstanding significantly influenced the project's direction. By communicating this goal early to the architect, the project was able to prioritise decisions aligned with this objective. For example, the decision to use locally sourced CLT materials from Åmot, produced by Splitkon, located 30 minutes from the construction site, was guided by the architects as advisors. This example demonstrates how a property owner with ambitious sustainability goals can effectively communicate them to their architects and advisors from the beginning of the project. This ensures that all decisions and priorities throughout the project consistently support those sustainability objectives.

6.1.2 Stakeholders

Throughout the interviews and discussions conducted over the semester, it became clear that the building owners had significant influence over the projects and their financial aspects. In the end, it emerged that the building owners who ordered the assignment included the type of way they wanted the project to be carried out in the detailed assignment description. This is also reflected in sustainable choices, as the builders usually make this decision. However, they can be influenced by various stakeholders, and through conversations at "Nordic Office of Architecture", it became clear that several architects specialised in sustainability and could, therefore, advise building owners on such sustainable strategies. However, there was no standard procedure for such a process. This may be attributed to the recent adaptation of regulations to the new TEK17 requirement mentioned in the theory Chapter (ref. Chapter 2.3), which mandates the preparation of a report on reusable materials. Currently, there are no specific requirements on how this should be carried out, which can be seen as a weakness in the new regulation.

While influential in project design, the building owners make the final decisions. Advisors, such as sustainability consultants and operations managers, also play significant roles in promoting material reuse by establishing standards, facilitating dialogues with suppliers and purchasers, and ensuring compliance with industry regulations. As end-users of constructed buildings, clients are increasingly interested in sustainability and are beginning to prioritise material reuse in their projects. Circular Economy and international initiatives could be the reason for this increased interest in sustainability.

Despite the fact that the majority of the informants in this thesis were positive about sustainable development, it is also important to mention the minority who see this as unnecessary. The construction industry is known for being an industry where development is slow compared to other industries. The literature search revealed that several believe that the industry has no need for green development and that concepts such as BREEAM and FutureBuilt are not necessary as they do not promote sustainability but rather become a kind of strategic game to achieve a high degree of certification and a good reputation. From the questionnaire, we see that 2 informants have chosen the response alternative *higher rental income and sales* from Figure 42. This can be interpreted as motivation based on these benefits. We also see this in the case study where "Spor X" has a high rental rate, which from the building owner can be explained by sustainable choices that you see tenants more and more demanding for their buildings in today's market. This shows that certain sustainable initiatives could be used as a strategic plan to gain more money for the project.

6.1.3 Interactions

The effectiveness of material reuse strategies is also influenced by the interactions between stakeholders. While there is generally good cooperation between building owners and advisors, time pressure often leads to other matters being prioritised. Contractors, in particular, often enter the project too late to participate meaningfully in decisions related to material reuse. However, there is a growing trend towards collaboration among stakeholders, driven by a shared commitment to sustainability. Positive sharing cultures are emerging, with increased knowledge-sharing among disciplines and collaboration on funding reuse projects. This collaborative approach is essential for overcoming the challenges associated with material reuse and for driving meaningful change within the construction industry. The case study at Odins Gate (Chapter 5.3) demonstrates that interacting with various areas within the project is advantageous for collaboration on topics such as reuse, as noted by the project architect from Nordic Office of Architecture.

An example of positive interaction is the project "Sirkulær Ressurssentral" (Chapter 2.7.1). This initiative is designed to be inclusive of all levels within the construction industry, with the goal of involving all fields because it is not clearly defined who holds the primary responsibility for reuse although the interview results revealed that building owners often perceive it as their responsibility to oversee reuse initiatives. The centre provides a platform where different stakeholders can collaborate and contribute to sustainability efforts. Advisors and architects typically noted that building owners hold significant power in making decisions related to reuse. Recognising this dynamic, the "Sirkulær Ressurssentral" was designed to address these issues by offering a space for building owners to rent for the temporary storage of materials. This space provides a practical solution for managing reusable materials and promotes better interaction among various stakeholders. This facilitates a more collaborative environment where materials can be reused more efficiently, reducing waste and promoting sustainability. The centre helps bridge the gap between different industry segments. According to interviewee 7, who is responsible for "Sirkulær Ressurssentral", it remains unclear which role within a construction project is actually accountable for reuse. As noted in the results, building owners often assume this responsibility since they make the financial decisions. Others believe that advisors should take a more significant role in such processes. This lack of clarity makes it difficult to define who the customer for initiatives like the "Sirkulær Ressurssentral" actually is, indicating that it would be beneficial to establish this definition.

In conclusion, effective communication, the roles played by different stakeholders, and their interactions are critical factors influencing the effectiveness of material reuse strategies in the construction industry. Close collaboration and ensuring that all stakeholders are engaged and informed will allow the construction industry to make significant steps towards achieving sustainability goals and reducing environmental impact.

6.2 What early-phase mapping solutions have been developed to date, and how do these function in practice?

6.2.1 Stakeholders Solutions

Advisors, such as sustainability coordinators and operations managers, are at the forefront of implementing these solutions. Interview Subject 4 mentioned that within their company, sustainability coordinators produce reports to show the degree of reuse in individual projects. Although there is no standard process for this reporting, the increasing desire for such a process is driven by new regulations and standards. Having sustainability advisors on a project is expensive and not always a priority. Having a more standardised process of reuse mapping could therefore be more effective, less expensive and will therefore be a solution for all types of projects. In addition to human-driven advisory, stakeholders are increasingly turning to digital tools and technologies to facilitate early-phase mapping and promote material reuse. Digital platforms like "Loopfront" and competition "DIPLOM" are gaining popularity for their ability to assist in early-stage mapping. Having these platforms could potentially also be beneficial in terms of costs. However, challenges such as minimal training on these programs and a lack of registered reusable materials pose significant barriers to their adoption.

Various methods were employed in the case studies. In Odins Gate 4, no digital modelling was used. This can be attributed to the project's small scale and its specific target group, Ukrainian refugees, who had an urgent need for quick assistance. The results indicated that developing digital models is often time-consuming. Interviewees from Nordic Office Of Architecture, who were also the architects behind Odins Gate 4, pointed out that they have no routine for such a process. This is likely one of the main reasons why this solution was not implemented in this case study. However, the lack of digital modelling at Odins Gate 4 may have limited the project's ability to foresee and mitigate issues early on. In the case study of Bærum Kommunegård, the results showed that a BIM model of the existing building was developed from an early stage. This can impact the project's speed both positively and negatively. On the positive side, once a digital model is in place, the project becomes more adaptable to changes, and such processes can occur more quickly. Previously, any changes required updates to all 2D drawings, but with a model, this can be done faster, and the drawings will automatically update using the most common software. On the negative side, creating such a model is both time-consuming and expensive. In contrast to the Odins Gate case study, where a model was not created, the Bærum Kommunegård project was of a completely different and larger scale. This demonstrates that the use of digital models is dependent on the project's size. While smaller projects might not justify the investment in a BIM model, larger projects can benefit significantly from the efficiencies and accuracy that digital modelling provides. This indicates that the decision to implement digital models should consider the project's scale and complexity to balance the initial costs against the potential long-term benefits.

BIM: Benefits and Challenges

The benefits of BIM extend beyond early-phase mapping. One of the primary advantages is the creation of a unified digital representation that integrates all aspects of a building, from architectural design to structural engineering and mechanical systems. This holistic approach ensures that all elements are considered in relation to each other, enhancing the overall coherence and functionality of the design. This will also be beneficial for future changes in the building. It provides a comprehensive database of the building's specifications and operational details, which can be used for maintenance, renovations, and energy management. This ongoing utility underscores BIM's role in supporting the entire lifecycle of a building. One significant challenge by using BIM is the initial investment required for software licenses, training, and infrastructure to implement BIM effectively. In addition, incompatibility between software tools can hinder collaboration and data exchange between project stakeholders, leading to inefficiencies and errors in project coordination. Moreover, data security and privacy concerns arise with the use of BIM, as these digital models contain sensitive information about buildings and infrastructure projects. Ensuring robust cybersecurity measures and implementing data protection protocols is crucial to safeguarding BIM data from unauthorised access or manipulation. Addressing these challenges will be critical in realising the full potential of BIM in the construction industry.

In conclusion, while BIM offers significant benefits such as improved project coordination, enhanced collaboration, and streamlined facility management, it also presents challenges. These include initial investment costs, interoperability issues, complexity of software, and concerns regarding data security and privacy. Despite these challenges, the widespread adoption of BIM is expected to continue, driven by its potential to revolutionise the construction industry and improve efficiency throughout the project lifecycle. Addressing these challenges through training, standardisation, and robust cybersecurity measures will be essential to maximising the benefits of BIM in construction projects.

Digital Platforms

Digital platforms for reuse mapping, exemplified by Loopfront, Materia, and Asplan Viak's Delio, offer innovative solutions for documenting and inventorying reusable materials in construction projects. Loopfront provides a cloud-based application facilitating the reuse, repair, redesign, and recycling of building materials. Similarly, Materia offers a mapping tool for listing materials via mobile phones, promoting practical reuse. Meanwhile, Asplan Viak's Delio enables efficient registration of reusable items in the field, streamlining post-processing information handling. These platforms enhance stakeholder collaboration and transparency by centralising data, simplifying the documentation process, and promoting sustainable practices in the construction industry.

These platforms offer numerous advantages for the construction industry. Firstly, they streamline the process of documenting and inventorying reusable materials, enhancing efficiency and reducing manual labor. Secondly, they promote stakeholder collaboration and transparency by centralising data and facilitating communication. Thirdly, they contribute to sustainability efforts by promoting reuse, repair, and recycling of building materials, thereby reducing waste and environmental impact. These platforms are still in the early stages of development, indicating significant potential for growth and improvement in the future. As they continue to evolve rapidly, they are poised to become even more beneficial for the construction industry, offering enhanced functionality and addressing emerging challenges. It is important to note that despite not being used in the relevant case studies for this assignment, we may see changes once these platforms have become more integrated within the larger companies that undertake such processes.

As these tools continue to evolve and gain acceptance within the industry, it is likely that their adoption will increase, leading to potential shifts in project approaches and methodologies. In addition to this, the potential of linking such processes to actual 3D and BIM models will provide an exciting new perspective on how to plan for reuse even before the project has started. Therefore, the development of these platforms will be of great benefit to future 2D and 3D modelling efforts.

6.2.2 Functionality and New Technology

The functionality of early-phase mapping solutions varies depending on the specific needs of stakeholders. Building owners, developers, and advisors are utilising technologies like laser scanning to digitise existing buildings and gather spatial data. Interviewee 6 mentioned the ongoing digitalisation of 33 school buildings to improve the quality of data for future development work. Advisors, such as Interviewee 3, described the process of sourcing foundational materials, pricing, and executing laser scanning to generate point clouds and BIM models. These technologies enable stakeholders to access accurate spatial data that can be used in multiple phases of a project, from planning to execution.

Emerging technologies are revolutionising early-phase mapping and material reuse in the construction industry. Interview Subject 7 discussed the establishment of physical storage stations equipped with logistics systems, allowing private individuals, clients, and contractors to buy and sell reused materials. These storage stations facilitate digital knowledge sharing and aim to promote the reuse of materials during the early phases of planning. Additionally, digital platforms are being developed to facilitate the exchange of reusable materials between stakeholders. However, the adoption of these new technologies is still in its early stages, and further efforts are needed to overcome challenges such as data interoperability and user training.

Physical Storage
The emergence of storage stations represents a growing trend on a national scale. Interviewee 7 mentioned that many stations are being established throughout Norway. Interviewee 6, who oversees the market in the north, confirmed this and underscored the Oslo station's status as the pioneering model, inspiring subsequent iterations. Notably, the recent establishment of the Oslo station highlights how new this concept actually is. This emerging trend significantly impacts operations and logistics, as evident from discussions with staff, highlighting the need for several adjustments to attain optimal workflow. For instance, the absence of a digital platform intended to complement physical storage infrastructure impedes efficient management, highlighting the interdependence of physical and digital advancements in attaining desired objectives. The increasing number of storage stations signifies a substantial paradigm shift towards supporting reuse and sustainability within the construction industry. However, the integration of digital tools with physical infrastructure is essential to manage the complexities involved. The Oslo station serves as a pioneering model, but the need for a robust digital system to track and manage materials effectively remains a critical challenge. Interviewees underscore the indispensable role of digital infrastructure in maximising the efficacy of storage station initiatives. The absence of a digital equivalent hinders the full potential of these initiatives.

This situation underscores the importance of developing comprehensive solutions that blend physical and digital strategies. Establishing a seamless digital platform will enhance the organisation and accessibility of materials as well as facilitate better coordination among stakeholders.

In conclusion, stakeholders are leveraging digital tools and technologies to gather spatial data, digitise existing buildings, and facilitate the exchange of reusable materials. However, challenges such as data interoperability, user training, and the lack of registered reusable materials pose significant barriers to the widespread adoption of these solutions. Moving forward, it is crucial for stakeholders to collaborate and invest in the development of user-friendly, interoperable digital platforms that promote material reuse and sustainability in the construction industry.

6.3 How can we facilitate increased reuse in the industry during the early stages of the project?

6.3.1 Facilitating for Increased Reuse

To facilitate increased reuse in the industry, stakeholders emphasised the need for stricter regulations, flexibility and increased use of digitalisation. Interview Subject 5 argued that processes need to be more systematically organised, with stricter government regulations to make things easier. There is a clear consensus among informants that the state must play a more significant role in facilitating reuse, similar to its role in other industries. Economic incentives and well-organised infrastructure were identified as significant drivers for enhancing opportunities for reuse.

Regulations
Numerous regulations and new requirements are designed to facilitate reuse. These requirements evolve with societal advancements. The results reveal that while these regulations can support reuse initiatives, they can also pose significant challenges. This new set of rules is meant to keep up with changes in society, where we observe a significant increase in the emphasis on sustainable development and the circular economy. In addition to this progression, construction methods have changed over time, and stricter safety standards for buildings mean that the ways we build today are different from those in the past. The results from the questionnaire and interviews show that regulations for sustainable development, along with safety requirements, often clash and slow down progress in various ways.

On one hand, initiatives such as BREEAM certifications, FutureBuilt priorities, TEK17 requirements, and other new measures have shifted the focus towards sustainability. As TEK17 evolves, there is a need to accommodate these new standards. These measures have positively influenced the approach to reuse. On the other hand, the regulations have also posed significant challenges to sustainability efforts. While visiting Odins Gate 4, the architect argued that the standards have become so rigorous that reusing old materials is often not feasible, as they no longer meet current standards. For example in the Odins Gate 4, the railing had to be completely replaced because its height and width did not comply with current regulations. Additionally, if reuse is desired, materials must undergo testing to ensure they are in adequate condition for reuse. Such testing is both costly and time-consuming and is not currently well-facilitated. This requirement can mean, as it stands today, more time and CO_2 emissions are spent transporting these materials to testing facilities than would be spent purchasing new materials. Thus, while regulations aim to support reuse, they also inadvertently create barriers that can make it less practical or sustainable in certain cases.

Despite BREEAM's intended positive contribution to the greener construction industry, there is scepticism surrounding the concept. This scepticism arises from concerns that BREEAM could be associated with "greenwashing", which refers to the deceptive portrayal of environmentally friendly practices for marketing purposes. The sceptical individuals argue that the concept may not contribute significantly beyond the status of having, for example, a BREEAM certification or sustainable materials. BREEAM has gained popularity nationally, with an increasing number of stakeholders seeking such certification. The concern about greenwashing reflects a broader scepticism within the industry about the effectiveness of sustainability certifications and initiatives.

Regardless of these concerns, BREEAM and similar certifications play a valuable role in promoting sustainability awareness and encouraging the adoption of environmentally friendly practices within the construction industry. While scepticism may exist, it is important to recognise the potential benefits of such initiatives and work towards ensuring that they are implemented with integrity and genuine commitment to sustainability principles. This requires ongoing evaluation and improvement of certification processes to maintain their relevance and effectiveness in driving positive environmental outcomes.

Flexibility
According to the interviews conducted, one of the biggest challenges regarding reuse in the construction industry is the lack of building flexibility in current building practices. Interview Subject 4 highlighted the need to build flexibly for the future, as the construction site of the future may look vastly different from what it does today. The COVID-19 pandemic has brought a conscious focus to this issue, emphasising the importance of adaptability and flexibility in construction projects. Informants agreed that flexibility is essential for facilitating reuse in the future. Flexibility can encompass many aspects, but from the viewpoint of interviewee 4, it primarily involves designing buildings for easy disassembly. This involves materials being welded together in such a way that they can be easily taken apart. This approach is crucial, given the rapid evolution of our modern society and the possibility that today's requirements might differ significantly from future needs. Therefore, buildings must be adaptable in their material composition, spatial positioning and in their intended functions.

Despite the emphasis on flexibility, the gaps identified from the literature review underscore that simply creating new flexible products without considering the broader resource utilisation is insufficient. This suggests the importance of taking a holistic view of projects. Pursuing flexibility often involves producing new materials. While this may ultimately be sustainable by enabling materials to be used in more diverse ways, it may also necessitate the production of a significant amount of new materials. Current prefabricated materials in buildings typically do not prioritise flexibility. This raises the discussion about the trade-off between higher emissions today to produce flexible and durable materials for the future versus utilising and reusing our existing materials. Nevertheless, instead of only focusing on new flexible materials, researchers can explore opportunities for flexibility within existing buildings. This involves investigating whether new methods can be developed to construct flexibility using old materials. By doing so, we can potentially reduce the need for new materials while also maximising the value and lifespan of existing resources. This dual approach, exploring both new materials and innovative uses for existing materials, allows for a more comprehensive and sustainable approach to achieving flexibility in construction projects.

Digitalisation
According to Interviewee 6, the potential of digital tools to optimise processes supports the need for digitisation to improve operational efficiency. This is supported by the positive responses in the questionnaire on the impact of digitalisation (Figure 49). The literature search findings highlighted a strong enthusiasm for BIM usage and its potential. Numerous researchers, for example Cinquepalmi et al. (2023), are developing algorithms to improve data processing efficiency, acknowledging that managing large datasets can pose challenges for current models. Notably, studies are focusing on automation and exploring the interplay between datasets, logistics, and materials (i.e. Xiong et al., 2013). Informant 3 expressed a strong belief that BIM technology would soon evolve, lead-

ing to more reuse opportunities. The technology is well underway, and with the new regulations, there will be an opportunity for new technology to adapt to forthcoming standards and facilitate sustainable requirements.

However, many in the construction industry struggle with the adoption of digital tools. The industry is known for its conservative nature, with changes and developments often taking considerable time. Despite this, there is considerable progress, with numerous startups and ongoing national efforts aimed at driving change. BIM has also become a vital tool in today's national and international construction projects, especially in the development of new buildings. This reflects a growing shift towards embracing digital tools and innovative practices. The integration of BIM models that better support reuse is seen as a key development. Informants and literature alike suggest that these advancements could transform how projects are managed, making them more sustainable and efficient. Yet, the conservative nature of the industry presents a barrier that must be overcome. Embracing digital tools and promoting innovation within traditional frameworks are essential steps toward achieving this transformation.

In conclusion, while challenges remain, particularly regarding the conservative nature of the construction industry and the complexity of handling large datasets, there is a clear trend towards greater digital integration and innovation. Continued research and development in BIM technology, alongside efforts to shift industry practices, will be essential in realising the full potential of these tools for promoting sustainability and reuse in construction.

6.3.2 Government Initiatives

Several informants expressed concerns about current regulations and emphasised the need to modify them to facilitate reuse effectively. Current regulations are often stricter than when the buildings to be demolished were constructed, making it challenging to reuse materials that do not comply with today's standards. There is a need for clearer wording around regulations and technical requirements, as well as documentation requirements that are easier to navigate. Greater standardisation and alignment of regulations are necessary to promote reuse effectively.

Transition to Circular Economy
As mentioned in Chapter 2.5, the Parliament will introduce new regulations derived from the 2024 action plan within the circular economy to transition society from its current linear model. With added emphasis on changes in the value chain, this will positively influence the construction industry by placing additional pressure on material consciousness.

Government Actions
The Norwegian government has recognised the importance of transitioning to a circular economy as a critical measure to reduce resource use and environmental impact. As mentioned in Chapter 2.3, in 2024, the government formulated a comprehensive action plan detailing strategies for transitioning from a linear to a circular economy. This plan outlines targeted measures to reduce waste and promote new value creation. The government's vision, as stated in the action plan, is for Norway to become a pioneering country in developing a green, circular economy that reduces environmental and climate burdens while creating new jobs. This vision is supported by updating public procurement regulations to include mandatory climate and environmental requirements.

These measures aim to increase demand for sustainable solutions and practices in the construction industry.

Despite these initiatives, stakeholders in the construction industry have identified several regulatory challenges that hinder the effective reuse of materials. Current regulations, often stricter than those in place when many existing buildings were constructed, create barriers to reusing materials that do not meet today's standards. This discrepancy highlights the need for regulatory reforms that facilitate reuse without compromising safety and performance. Stakeholders have called for clearer wording around regulations and technical requirements and more straightforward documentation processes. Standardising and aligning regulations can significantly enhance the feasibility of reuse in construction projects. The government can encourage broader adoption of circular economy principles and practices by simplifying the regulatory landscape.

In the chapter titled Contracts and Impact (2.4.1), depicted in Figure 10, it is evident that the potential for influence drops quickly following the "programming" stage. This observation underscores the significance of making decisions at the earliest possible stage, thereby supporting the inclusion of sustainability requirements in the initial order prior to the commencement of the project. In the context of government procurement, sustainability objectives could be integrated into the order, compelling contractors to incorporate these considerations into their bids. This would lessen the emphasis on price competition, as all bids would include the same requirements and associated costs.

6.3.3 Long-Term Vision

Stakeholders envision a future where digitalisation plays a central role in facilitating increased reuse in the construction industry. Interviewees highlighted the need to make greater use of digital tools, such as laser scanning, to create catalogues of reusable materials and establish alert systems. However, the industry still requires a more robust digital framework. Despite some progress, significant efforts are still needed to enhance reuse practices and achieve the industry's sustainability goals.

Additionally, the majority of respondents in the questionnaire indicated that current regulations do not align with the desire for reuse. This barrier makes it difficult to initiate a reuse process, as respondents interpreted the regulations as challenging to navigate. In addition, many of the interviewees emphasised the importance of government support in the form of financial incentives to make reuse economically viable. As mentioned, several respondents cited subsidies for electric vehicle usage as an example, suggesting that a similar scheme should be implemented to support reuse initiatives.

Combining Technologies
It is interesting to explore the combination of various emerging technologies entering the market. For instance, laser scanning and physical storage are two innovations that could eventually be combined to digitise and tag used materials in a building even before it is demolished.

One potential approach to combining new technologies is to integrate laser scanning with physical storage. This concept is outlined in Figure 55. As mentioned by Interviewee 7, physical storage is progressing, but it is currently facing challenges in establishing digital infrastructure. Consequently, the logistics aspect is sub-optimal, making the process more difficult. Additionally, Interviewee 3 noted that laser scanning is becoming increasingly popular. This technology involves scanning old buildings to create a digital twin, providing an overview of the building's structure. As mentioned by Interviewee 6, building owners are increasingly utilising this technology, with specific reference to scanning school buildings. Figure 55 presents an interpretation of these concepts, divided into three steps. Step 1 involves scanning an old building to create a digital representation and to index materials that need to be documented according to current regulations. Subsequently, this information is transferred to a digital platform, providing constant access to materials that can be reused. The crucial step is Step 3, where materials, after the demolition phase, are stored in a physical storage station with the same markings as in their digital model. This process enhances efficiency.

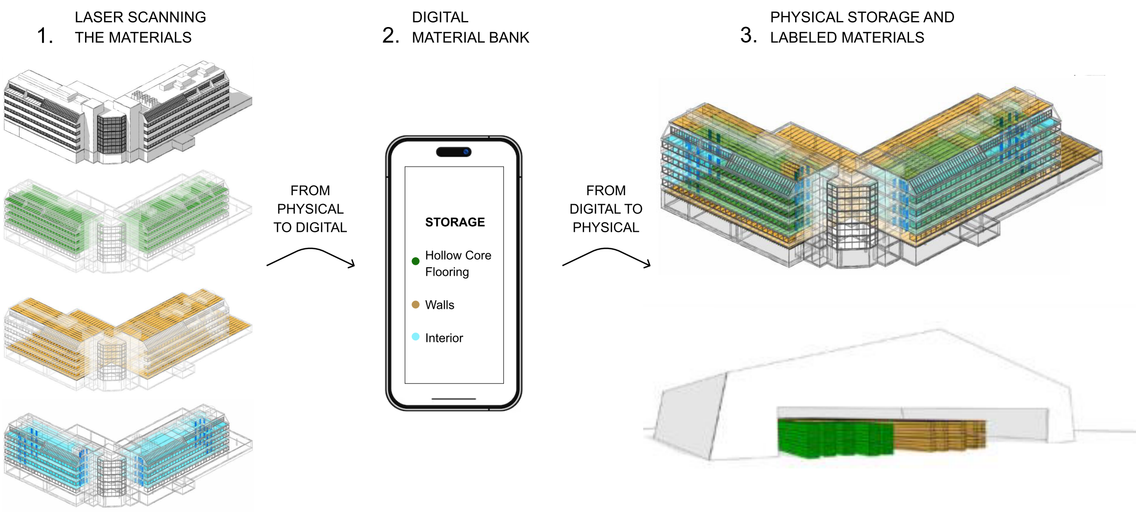

Figure 55: Possible Solution and relationship between 1. laser scanning, 2. digital material bank and 3.physical storage and labeled materials.

However, it is not certain whether current technology allows for indexing materials during the scanning process. This area is relatively new, having only gained attention in recent years. Nevertheless, it is intriguing to attempt to integrate these new technologies to find a comprehensive solution. This is particularly interesting considering the highly fragmented nature of the construction industry, as emphasised by many of the interviewees and supported by the literature. Technological advancements are progressing rapidly, now incorporating 360°imagery (ref. Figure 15), significantly enhancing digital spatial comprehension compared to previous capabilities.

In conclusion, facilitating increased reuse in the construction industry during the early stages of a project requires flexibility, systematic organisation, regulatory changes, and greater digital alignment. By addressing these challenges and opportunities, stakeholders can work together to promote sustainability, reduce environmental impact, and create a more circular economy in the construction industry.

7 Conclusion

This chapter presents the main findings from the research methodologies outlined in Chapter 5. It presents these findings in bullet points to enhance readability and facilitate practical use by readers. The main objective of this thesis was to address the question:

"How can digital mapping improve material reuse in Norwegian construction projects?"

The question was examined through three specific research questions mentioned in Chapter 1.2. The chapter concludes with key findings and proposes avenues for future work.

7.1 Main Findings

1. **Combining technologies for comprehensive solutions:**
   The adoption of emerging technologies can revolutionise early-phase mapping and material reuse. Laser scanning creates digital twins of existing buildings, providing detailed spatial data that can be used to identify and catalogue reusable materials. This technology, combined with physical storage solutions, can create a seamless process for managing reusable materials. For example, scanning a building before demolition can label materials for reuse, which are then stored in physical storage stations with corresponding digital records. This integration ensures efficient management and accessibility of reusable materials, promoting sustainability and reducing waste.

2. **Early-phase mapping and planning:**
   Digital tools and new technologies, particularly BIM and other digital platforms like *Loopfront* and the *DIPLOM* project, play an important role in the future of early-phase mapping and promoting material reuse. These platforms facilitate the documentation and inventory of reusable materials, reducing the need for manual labour. The Bærum Kommunegård case study illustrated the benefits of using a BIM model, which allowed for more adaptable and efficient project management. Although developing digital models can be time-consuming and costly, their long-term benefits, such as enhanced accuracy and efficiency, outweigh the initial investment, especially for larger projects. However, for smaller projects, scalable and cost-effective digital tools are needed to provide similar benefits without imposing significant financial burdens.

3. **Enhancing communication and stakeholder collaboration:**
   The importance of communication among stakeholders for successful material reuse is underscored in the thesis. Encouraging collaboration and knowledge sharing between the construction industry will leverage insights and best practices from different fields. Digital tools play a crucial role in facilitating communication by providing a centralised platform for information sharing. This integration ensures that all stakeholders, including architects, building owners, and advisors, have access to the same data, leading to better collaboration.

4. **Regulatory support and government initiatives:**
   Current regulations frequently hinder material reuse due to strict safety and sustainability standards. The Norwegian government's action plans aim to transition to a circular economy, but current regulations need alignment with practical reuse goals. The study revealed

that there is a need for clearer regulations and standardised processes to facilitate reuse effectively. The integration of digital tools can support regulatory changes by offering robust documentation and traceability of materials, ensuring that reused materials meet the required standards. In addition, there is a consensus on the requirement for more robust government intervention to support reuse through incentives and infrastructural provisions.

5. **Training and education programs:**
   Developing training and education programs to learn the digital and technical skills of construction professionals, is important and will enable them to effectively utilise digital mapping solutions.

6. **Economic incentives for reuse practices:**
   Government support is crucial for promoting material reuse. The Norwegian Action Plan for Construction and Demolition Waste sets national objectives for waste reduction and material recycling. However, stakeholders have identified regulatory challenges that hinder reuse. Simplifying the regulatory landscape and providing economic incentives, similar to subsidies for electric vehicles, can encourage broader adoption of reuse practices. Digital mapping tools can play a pivotal role in meeting these regulatory requirements by providing accurate data and facilitating compliance.

7. **Contracts:**
   Today's traditional design-build contracts are not suitable for efficient reuse projects. They often lack the flexibility and collaboration needed to incorporate sustainable practices and the reuse of materials efficiently. Introducing design-build contracts with a reward system for material reuse and reduced greenhouse gas emissions would address the limitations of current traditional contracts.

8. **Decisions:**
   It is crucial to establish a standard for when sustainability decisions should be made. The thesis indicates that the project's influence diminishes rapidly and is nearly absent when the project is ready to commence construction. Therefore, it may be advisable to always include such requirements in the client's project brief. In addition, in current projects, it's often unclear who is responsible for making sustainable decisions, especially in projects without sustainability coordinators. Therefore, in future projects, it's crucial to establish who should take charge of influencing sustainability decisions.

9. **Long-term vision and sustainability goals:**
   The development and adoption of user-friendly, interoperable digital platforms are essential for promoting sustainability and material reuse, overcoming conservative tendencies within the industry to achieve significant progress. We must not view sustainability and digitisation as separate entities; instead, we should see sustainability as a result of digitisation.

10. **Need for Standardisation:**
    The necessity for standardisation, particularly in digital tools and material reuse, is frequently highlighted. This ensures collaboration and data exchange among stakeholders, thereby facilitating the seamless integration of mapping solutions into construction workflows. To avoid the perception of "greenwashing", it's crucial to implement transparent monitoring and evaluation methods for concepts promoting sustainable choices like BREEAM and Futurebuilt.

11. **Flexibility for old materials:**
    Investigating the development of new methods to introduce flexibility using old materials in already produced buildings can potentially reduce the reliance on new materials while maximising the value and lifespan of existing resources. This dual approach, exploring both innovative uses for current materials and considering new materials, offers a simpler and more sustainable way to achieve flexibility in construction.

7.2 Further Work

Future research should explore the development of a digital framework that integrates with physical storage locations. The findings of this study demonstrate that both digital transformation and the establishment of physical storage facilities for materials are currently in progress. Therefore, it is crucial to establish a connection between these two domains. Additionally, the government's role in influencing future construction projects should be further examined. This study highlights instances where the government provides financial incentives, which could impact the construction industry. Furthermore, it is important to investigate the implementation process of this integration and identify the responsible segments of the value chain. The field of digitisation and reuse is still relatively new, so moving forward, it will be important to align these areas to uncover new opportunities within the industry.

Moreover, future studies should examine the scalability of digital mapping solutions across various project sizes and types. While larger projects may benefit significantly from comprehensive digital models, smaller projects might face budget constraints that limit the adoption of such technologies. Research should aim to create cost-effective digital tools that can be adapted to the needs of smaller projects without losing their effectiveness. Additionally, it is crucial to examine how well different digital platforms can work together to ensure smooth data exchange and integration across the construction industry. This includes investigating the potential for open-source solutions that can reduce entry barriers and encourage innovation. Finally, the long-term effects of digital mapping on sustainability should be assessed to understand how these technologies help reduce waste and promote a circular economy. This will provide insights into the broader environmental benefits and guide policy decisions to support sustainable construction practices.

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Appendix

A Literature Review References

B Questionnaire

C Questions for Semi-structured Interviews

A Literature Review References

NR.	YEAR	TITLE	AUTHOUR(S)
1	2024	*Registration of oblique photography point clouds with terrestrial laser scanning point clouds based on geometric features of irregular building*	Xu, JH and Xu, Jinghai
2	2024	*The adaptive reuse design strategies– focused on the case of the Tate Modern architectural competition*	Shin, Y.-J.
3	2023	*Efficiency and Sustainability: The Role of Digitization in Re-Inhabiting the Existing Building Stock*	Cinquepalmi, F., Paris, S., Pennacchia, E., Tiburcio, V.A.
4	2023	*Circular economy in the heritage conservation sector: An analysis of circularity degree in existing buildings*	Dişli, G., Ankaralıgil, B.
5	2023	*Adaptive reuse of existing buildings as a sustainable tool for climate change mitigation within the built environment*	Aigwi, I.E., Duberia, A., Nwadike, A.N.
6	2023	*Adaptive Re-Use of Historic Covered Markets: A Review of Selected Cases in European Capital Cities*	Bianco, L.
7	2023	*Circular building adaptability in adaptive reuse: multiple case studies in the Netherlands*	Hamida, M.B., Remøy, H., Gruis, V., Jylhä, T.
8	2023	*Embodied energy in existing buildings as a tool for sustainable intervention on urban heritage*	Guidetti, Elenaa., Ferrara, Maria
9	2023	*Struggles over waste: Preparing for re-use in the Danish waste sector*	Moalem, R.M., Remmen, A., Hirsbak, S., Kerndrup, S.
10	2022	*An adaptive down-sampling method of laser scan data for scan-to-BIM*	Qiu, Q.,Wang, MJ., Ziwen, L., Guo, J., Wang, Q
11	2022	*Circular Economy in Construction and Demolition Waste Management in the Western Balkans: A Sustainability Assessment Framework*	Nadazdi, A., Naunovic, Z and Ivanisevic, N
12	2022	*Realising the sustainable development goals through organisational learning and efficient resource management in construction*	Opoku, A., Ahmed, V and Ofori, G
13	2022	*Structural Stability Evaluation of Existing Buildings by Reverse Engineering with 3D Laser Scanner*	Jang, A., Ju, YK and Park, MJ
14	2022	*A cost-effective recycled aggregates classification procedure for construction and demolition waste evaluation*	Ferriz-Papi, JA., Weekes, E., Whitehead, N., Lee, A
15	2022	*Scan-to-BIM technique in building maintenance projects: practicing quantity take-off*	Sing, MCP., Sophie, YYL., Chan, K, H, C., Liu, H, J., Humphrey, R
16	2022	*Contributions of the circular economy to the UN sustainable development goals through sustainable construction*	Ogunmakinde, OE., Egbelakin, T and Sher, W
17	2022	*A Methodology to Qualitatively Select Upcycled Building Materials from Urban and Industrial Waste*	Parece, S., Rato, V., Resende, R., Stellacci, S
18	2022	*Adaptive re-use of industrial heritage and its role in achieving local sustainability*	Alavi, P., Sobouti, H., Shahbazi, M.
19	2022	*Investigation of AEC/FM practices in adaptive reuse projects*	Hamida, M.B., Hassanain, M.A.
20	2022	*Industrial building adaptive reuse for museum. Factors affecting visitors' perceptions of the sustainable urban development potential*	Vardopoulos, I.
21	2022	*Evaluation of an interactive visualization tool to increase energy literacy in the building sector*	Henni, S., Franz, P., Staudt, P., Peukert, C., Weinhardt, C.
22	2022	*Material intensity database for the Dutch building stock: Towards Big Data in material stock analysis*	Sprecher, B., Verhagen, T.J., Sauer, M.L., Baars, M., Heintz, J., Fishman, T.
23	2021	*3D Modeling of Both Exterior and Interior of Traditional Architectures by Terrestrial Laser Scanning at Multi-Stations*	LEE, Jin-Duk., Bhang, Kon Joon and Schuhr, Walter
24	2021	*Monitoring the Beirut Port Silos' Structural Health Response a Few Months after Blast Loading Using 3D Laser Scan*	Ismail, S., Raphael, W and Durand, E
25	2021	*Downcycling and upcycling in rehabilitation and adaptive reuse of pre-existing buildings: Re-designing technological performances in an environmental perspective*	Scolaro, A.M., De Medici, S.
26	2021	*A graph based Monte Carlo simulation supporting a digital twin for the curatorial management of excavation and demolition material flows*	Züst, S., Züst, R., Züst, V., Stoll, S., Stoll, O., Minonne, C.
27	2021	*BIM-based Cultural Heritage Asset Management Tool. Innovative Solution to Orient the Preservation and Valorization of Historic Buildings*	Piaia, E., Maietti, F., Di Giulio, R., Schippers-Trifan, O., Van Delft, A, B., Bruinenberg, S., Olivadese, R.
28	2020	*Application of 3D Laser Scan Technology in the Surveying and Mapping of Ancient Buildings*	Xu, FJ and Chen, SK
29	2020	*Study of Possibilities of Using Special Types of Building and Demolition Waste in Civil Engineering*	Drochytka, R., Dufek, Z., Michalcíková, M., Hodul, J
30	2020	*Pathways to circular construction: An integrated management of construction and demolition waste for resource recovery*	Ghaffar, SH., Burman, M and Braimah, N
31	2020	*A definition framework for building adaptation projects*	Shahi, S., Esnaashary Esfahani, M., Bachmann, C., Haas, C.
32	2020	*The importance of place and authenticity in adaptive reuse of heritage buildings*	Yazdani Mehr, S., Wilkinson, S.
33	2020	*Information Reuse for Importance Sampling in Reliability-Based Design Optimization*	Chaudhuri, A., Kramer, B., Willcox, K.E.

34	2020	*A selective disassembly multi-objective optimization approach for adaptive reuse of building components*	Sanchez, B., Rausch, C., Haas, C., Saari, R.
35	2020	*Construction and demolition waste recycling in Europe: Long-term trends and challenges ahead*	Basuyau, V.
36	2020	*Circular economy strategies for adaptive reuse of cultural heritage buildings to reduce environmental impacts*	Foster, G.
37	2019	*M-estimator samle consensus planar extraction from image-based 3D point cloud for building information modelling*	Pleansamai, K and Chaiyasarn, K
38	2019	*Prototypology for a circular building industry: the potential of re-used and recycled building materials*	Heisel, F., Schlesier, K and Hebel, DE
39	2019	*Scan to BIM Beyond a Final BIM: Why, When and How*	Sarmiento, JC., Bercero, AM., Fernandez, JC., Garcia-Almirall, P
40	2019	*Increasing the efficiency and efficacy of demolition through computerised 4D simulation*	Kunieda, Y., Codinhoto, R and Emmitt, S
41	2019	*A digital construction framework integrating building information modeling and reverse engineering technologies for renovation projects*	Ding, ZK., Liu, S., Liao, LH., Zhang, L
42	2019	*Must Protection Stop Revitalization?*	Hrynyszyn, BD
43	2019	*“Deconstruction programming for adaptive reuse of buildings”*	Sanchez, B., Rausch, C., Haas, C.
44	2018	*Construction and demolition waste best management practice in Europe*	Gálvez-Martos, JL., Styles, D., Schoenberger, H., Zeschmar-Lahl, B
45	2018	*Automated Point Cloud Registration Using Visual and Planar Features for Construction Environments*	Kim, P., Chen, JD and Cho, YK
46	2018	*4-Plane congruent sets for automatic registration of as-is 3D point clouds with 3D BIM models*	Bueno, M., Bosché, F., Arias, P
47	2018	*Nearly zero energy building renovation: From energy efficiency to environmental efficiency, a pilot case study*	Brambilla, A., Salvalai, G., Imperadori, M., Sesana, MM
48	2017	*Virtual prototyping and validation of cpps within a new software framework*	Neumeyer, Sebastian., Exner, Konrad., Kind, Simon., Hayka, Haygazun., Stark, Rainer
49	2016	*A scientometric review of global BIM research: Analysis and visualization*	Zhao, XB
50	2016	*Developments in life cycle assessment applied to evaluate the environmental performance of construction and demolition wastes*	Bovea, MD and Powell, JC
51	2015	*An approach to combine progressively captured point clouds for BIM update*	Gao, T., Akinci, B., Semiha, E., Garrett, J
52	2015	*A decision support tool for the adaptive reuse or demolition and reconstruction of existing buildings*	Sfakianaki, E., Moutsatsou, K.
53	2014	*Sustainable construction with repurposed materials in the context of a civil engineering-architecture collaboration*	Sieffert, Y., Huygen, JM and Daudon, D
54	2013	*Automatic creation of semantically rich 3D building models from laser scanner data*	Xiong, XH., Adan, A., Akinci, B., Huber, D
55	2013	*Building your content reuse strategy*	McClure, M.
56	2011	*Optimizing Urban Material Flows and Waste Streams in Urban Development through Principles of Zero Waste and Sustainable Consumption*	Lehmann, Steffen
57	2011	*Recycling construction waste | Baustoffrecycling*	Müller, A.
58	2008	*The conservation, refurbishment and re-use of buildings*	Bowles, Robert P.
59	2007	*A qualitative approach to exploring adaptive re-use processes*	Kurul, E.
60	2004	*Managing waste at the residential construction site*	Laquatra, J., Pierce, M.
61	2003	*Sustainable management of demolition waste - an integrated model for the evaluation of environmental, economic and social aspects*	Klang, A., Vikman, PA and Brattebo, H
62	2003	*Design for decommissioning*	Hicks, David Ian
63	1999	*De-coupling for re-use in design and implementation using virtual sensors*	Hardy, N., Ahmad, A.
64	1993	*Disassembly within the scope of recycling*	Seliger, G., Kriwet, A.
65	1994	*Waste from construction and duty of care*	Ferguson, J
66	1984	*Revival in Europe (reuse of old buildings).*	Addis, B
67	1981	*New uses for old buildings.*	Montagu Of Beaulieu, L.

B Questionnaire

Early phase mapping to facilitate for potential re-use in the Norwegian building stock.

NTNU Masteroppgave vår 2024:
"Tidlig fase kartlegging for å tilrettelegge for potensiell gjenbruk i den norske bygningsmassen."

Svarfrist: 20.April (men jo før jo bedre) :-)
____

Denne undersøkelsen er en del av Ingeborg Pahle Strømsnes sin masteroppgave våren 2024 ved NTNU, som utforsker gjenbruk, digitalisering og reguleringer i hele bransjen.

Datainnsamlingen baserer seg utelukkende på deltakernes samtykke. Deltakelse er frivillig, og du kan trekke deg fra spørreundersøkelsen når som helst uten forklaring. Når den er sendt inn, blir data automatisk anonymisert og kan ikke spores tilbake til enkeltpersoner, noe som gjør tilbaketrekking etter innsending umulig. Ingeborg Pahle Strømsnes og hennes veileder, professor Gearóid Lydon ved NTNU, vil være de eneste som har direkte tilgang til rådataene.

Deltakernes navn vil ikke være gjenkjennelige i noen publikasjon. For spørsmål eller merknader om datainnsamling, kontakt NTNU's personvernombud, Thomas Helgesen (thomas.helgesen@ntnu.no), eller Sikts personverntjenester (https://www.nsd.no/personverntjenester/). Enhver deltaker kan sende inn en klage til Datatilsynet. Prosjektet er planlagt å avsluttes innen 01.07.24.

Ved å velge "Send" på slutten av spørreundersøkelsen, samtykker du til publisering av dine anonymiserte svar.

For andre henvendelser, tanker eller refleksjoner, send meg gjerne en mail: ingebps@stud.ntnu.no

____

English:

This survey forms part of Ingeborg Pahle Strømsnes' 2024 spring master's thesis at NTNU, exploring reuse, digitalization, and regulations across the entire industry.

Data collection relies solely on participant agreement. Participation is voluntary, and you may withdraw from the questionnaire at any time without explanation. Once submitted, data is automatically anonymized and cannot be traced back to any individual, making withdrawal post-submission impossible. Ingeborg Pahle Strømsnes and her supervisor, Professor Gearóid Lydon at NTNU, will be the only ones with direct access to the raw data.

Participants' names will not be recognizable in any publication. For queries or remarks about data collection, contact NTNU's privacy officer, Thomas Helgesen (thomas.helgesen@ntnu.no), or Sikt's data protection services (https://www.nsd.no/personverntjenester/). Any participant may lodge a complaint with the Norwegian Data Protection Authority. The project is scheduled to conclude by 01.07.24.

By selecting "Send" at the questionnaire's end, you consent to the publication of your anonymized responses.

For other inquiries, thoughts, or reflections, please feel free to email me at ingebps@stud.ntnu.no.

Response deadline: April 20 (but the sooner, the better) :-)

ingebps.stud.ntnu@gmail.com Switch account

Not shared

* Indicates required question

Hvor gammel er du? (What is your age?) *

Your answer

Hvilken kjønnsidentitet identifiserer du deg som? (What is your gender?) *

- Kvinne (Female)
- Mann (Male)
- Annet (Other)
- Foretrekker å ikke svare (prefer not to respond)

Hvilket land arbeider du i? (What country are you employed in?) *

- Norge (Norway)
- Annet (Other)

Hvis "Norge", hvor i Norge arbeider du (fylke)? (If "Norway", where in Norway do you work?)

- ◯ Oslo
- ◯ Troms og Finnmark
- ◯ Nordland
- ◯ Trøndelag
- ◯ Møre og Romsdal
- ◯ Vestland
- ◯ Rogaland
- ◯ Agder
- ◯ Vestfold
- ◯ Innlandet
- ◯ Akershus
- ◯ Østfold
- ◯ Buskerud
- ◯ Telemark

Kan du skrive postnummer for din hovedarbeidsplass? (Please write the postcode for your main workplace?)

Your answer

Hvis "annet", hvilket land? (If other, what country is this?)

Your answer

Hva er din rolle i planleggingsprosessen av et prosjekt? (What is your role in the planning process of a project?) *

- [ ] Byggherre, privat sektor (Client private sector)
- [ ] Byggherre, offentlig sektor (Client public sector)
- [ ] Arkitekt / designer (Architect/designer)
- [ ] Hovedentreprenør (Main Contractor)
- [ ] Underentreprenør (Sub contractor)
- [ ] Rådgiver, konstruksjon (Advisor, Construction)
- [ ] Rådgiver, bærekraft (Advisor, Sustainability)
- [ ] Rådgiver, andre felt (Advisor, other fields)
- [ ] Start-up selskap (Start-up company)
- [ ] Logistikk (Logistics / supply chain)
- [ ] Økonomi / finans (Finances)
- [ ] Leverandør (Supplier)
- [ ] Rivearbeid / avfallshåndtering (Demolition / Waste Management)
- [ ] Annet (Other)
- [ ] Forskning (research)

Hvis "annet", hvilken rolle? (If other, what role?)

Your answer

Hvilke type prosjekter har du vært mest involvert i? (What type of structures have you been involved with the most?) *

- Bygg under 5 etasjer (buildings under 5 floors)
- Bygg over 5 etasjer (buildings above 5 floors)
- Infrastruktur (infrastructure)
- Landskap (landscaping)
- Annet (other)

Hvis "annet", hvilke prosjekt? (If other, what projects?)

Your answer

Har du jobbet med ombruk- eller gjenbruksprosjekt før? (Have you worked with reuse of building materials before?) *

- Ja (yes)
- Nei (no)

Hvis ja, hva har vært motivasjonen til å gjøre det? (If yes, what has been you / your companys motivation to do so?)

- [ ] Økonomiske fordeler (Financial benefits)
- [ ] Godt rykte i bransjen (Positive reputation)
- [ ] Bestilling fra byggherre eller noen andre eksterne (Order from client or externals)
- [ ] Samfunnsansvar (Social responsibility)
- [ ] Ønske om å være bærekraftig (Desire to be sustainable)
- [ ] Høyere leieinntekter eller salg (Higher rental income or sale)
- [ ] Krav / reguleringer (Demands or regulations from the goverment)
- [ ] Breeam Sertifisering (Breeam Certification)
- [ ] Annet (other)

Hvis "annet", hvilken motivasjon? (If other, what motivation?)

Your answer

Kan du beskrive hvordan din rolle/arbeidsgiver arbeider med bærekraft slik det er i dag? (Can you describe how your role/employer works with sustainability as it is today?)

Your answer

Hva mener du er hovedutfordningene til et vellykket ombruks/transformasjonsprosjekt? (What are your thought on main barrier for a successfull reuse project?) *

- [ ] Reguleringer / krav (regulations)
- [ ] Kostnader (cost)
- [ ] Interesse/motivasjon (interest/motivation)
- [ ] Fordeler (Benefits)
- [ ] Logistikk (logistics)
- [ ] Dokumentering (documentation)
- [ ] Kunnskap (knowledge)
- [ ] Holdninger i bransjen (attitude)
- [ ] Tid (time)
- [ ] Kommunikasjon (communication)
- [ ] Annet (other)

Hvis annet, hva da? (If others, what?)

Your answer

17 I hvilken grad ser du gjenbruk av materialer som mulig i dagens byggebransje? (To what degree do you see reuse of materials as feasible in today's building industry?) *

	1	2	3	4	5	
Veldig Lav (very low)	○	○	○	○	○	Veldig Høy (very high)

Med dagens regelverk, i hvilken grad ser du utslippene fra nye materialer som en begrensende faktor i planleggingsprosessen av et prosjekt? (With current regulations, to what degree do you see the emissions from new materials as a limiting factor in the planning process of a project?) *

	1	2	3	4	5	
Veldig lav (very low)	○	○	○	○	○	Veldig høy (very high)

I hvilken grad mener du at regelverket i dag er strengt nok i forhold til krav om ombruk? (To what degree do you think that the regulations today are strict enough in relation to requirements for re-use?) *

	1	2	3	4	5	
Ikke strengt (not strict)	○	○	○	○	○	Veldig strengt (very strict)

Per i dag, i hvilken grad ser du barrierer (1) og pådrivere (5) i følgende kategorier for gjenbruk: (As of today, to what extent do you see barriers (1) and drivers (5) in the following categories for reuse) *

	Stor barriere (major barrier)	Moderat barriere (moderate barrier)	Nøytral (neutral)	Moderat driver (moderate driver)	Stor driver (major driver)
Reguleringer (regulations)	○	○	○	○	○
Kostnader (cost of materials)	○	○	○	○	○
Design	○	○	○	○	○
Konstruksjon (Structure)	○	○	○	○	○
Logistikk (Logistics)	○	○	○	○	○
Dokumenteringskrav (Documentation)	○	○	○	○	○
Utslipp (emissions)	○	○	○	○	○
Kunnskap (knowledge)	○	○	○	○	○
Motivasjon (Motivation)	○	○	○	○	○
Tid (time)	○	○	○	○	○
Annerkjennelse (recognition)	○	○	○	○	○
Andre ting (others)	○	○	○	○	○

For å sikre at du følger med på denne undersøkelsen, velg alternativ 4 på skalaen. (If you are paying attention to the questionnaire, please choose the option 4 on the linear scale) *

1 2 3 4 5

Hva er forventet pris på et gjenbruksmateriale ift. et nytt? (What would be the expected average price of a reused component compared to new) *

- Likt (equal)
- Høyere (->150%) higher
- Veldig mye høyere (150%->) Significantly higher
- Lavere (lower)
- Vet ikke (unsure)

I hvilken grad mener du digitalisering vil positivt påvirke morgendagens gjenbruksmuligheter? (To what extent do you believe digitalization will impact the potential for sustainability in the future?) 1 (low) - 5 (high) *

1 2 3 4 5

Mener du at det er god nok kommunikasjon på tvers av fag og avdeling i bransjen? (Do you think that there is good enough communication across subjects and departments in the industry?) *

- Ja (yes)
- Nei (no)

Mener du at Staten og regelverk er godt nok for å drive med ombruk? (Do you believe that the government and current regulations are sufficient to support the practice of reuse?) *

- Ja (yes)
- No (nei)
- Verken enig eller uenig (both)

Hvis nei, hva mener du må gjøres? (If no, what do you believe has to be done?)

Your answer

Tusen takk for din deltagelse. //
Thank you very much for your participation.

Til slutt, har du noen andre tanker rundt dette temaet? // Finally, do you have any other thoughts on this topic?

Your answer

Submit Clear form

C Questions for semi-structured Interviews

Interview guide
Ingeborg Pahle Strømsnes
NTNU, 2024

NTNU
Norwegian University of Science and Technology

Background:

The interview is carried out by MSc student Ingeborg Pahle Strømsnes within Sustainable Architecture at the Department of Architecture and Technology, at NTNU. The theme of the master's thesis is reuse and how it can be facilitated through digitalization and cross-disciplinary communication. The thesis is titled (current), but might be change until deadine:

"Early Phase Mapping to Facilitate for Potential Re-Use in the Norwegian Building Stock."

It is followed by three research questions:

1) How do stakeholder roles and interactions influence the effectiveness of material reuse strategies in the construction industry?
2) What early-phase mapping solutions have been developed to date, and how do these function in practice?
3) How can we facilitate increased reuse in the industry during the early stages of the project?

Use (interview):

The interview is intended for thematic mapping, prioritizing insights based on personal experiences and reflections. Outcomes will include proposed interventions and enhancements within the industry. The interview will be recorded for transcription purposes; all materials will be responsibly disposed of after the thesis's completion. Consent for recording and the use of anonymous quotes in the thesis will be confirmed with the interviewee.

Language:

The interviewee can choose whether the conversation should be in Norwegian or English.

Rights:

It is possible to contact the author, Ingeborg Pahle Strømsnes, throughout the period leading up to the completion of the master's thesis at the end of May. Additional thoughts and comments are always welcome, but there will also be the option to withdraw one's interview.

Interview guide
Ingeborg Pahle Strømsnes
NTNU, 2024

ENGLISH VERSION:

QUESTIONS (r.q = research question)

Background:

- What company do you work for?
- What is your current position?
- What is the size range of the projects you work on?

Re-use & mapping:

- How can you influence projects in terms of reuse in your role? (r.q.1)
- In your opinion, how does stakeholders interact in terms of reuse in the industry? (r.q.1)
- What methods do you/your company use in your projects to achieve successful reuse projects? Any digital software's or external mapping solutions? (r.q.2)
- Can you please explain how these methods play out in practice in a "typical" construction project? (r.q.2)
- From your perspective in the industry, what do you think is our biggest challenge when it comes to reuse in construction projects? (r.q.3)
- From your perspective, how can we facilitate for increased reuse in the industry? (r.q.3)

Regulation:

- What do you believe needs to be done with regulations to facilitate reuse? (r.q.3)
- How do you adhere to industry regulations, particularly in relation to BREEAM, TEK17 requirements, FutureBuilt, and other new regulations or recommendations that have emerged? Any other worth mentioning? (r.q.1,2,3)

Digitalization:

- Does your organization focus on digitalization in projects? (r.q.1,2,3)
- If yes, how is this implemented? (r.q.1,2,3)
- How do you think digitalization can facilitate increased reuse? (r.q.1,2,3)

Extra:

- Do you have any other thoughts that are important to mention regarding this topic?
- Where do you think we will be in 10 years in this area? (r.q.3)

Interview guide
Ingeborg Pahle Strømsnes
NTNU, 2024

NORWEGIAN VERSION:

SPØRSMÅL (r.q = research question)

Bakgrunn:

- Hvilket selskap jobber du for?
- Hva er din nåværende stilling?
- Hva er størrelsesomfanget på prosjektene du jobber med?

Gjenbruk & kartlegging:

- Hvordan kan du i din rolle påvirke prosjektene i forhold til gjenbruk? (r.q.1)
- Hvordan mener du at samarbeid på tvers av dag foregår ift gjenbruk? (r.q.1)
- Hvilke metoder bruker du/deres selskap i prosjektene deres for å oppnå gode gjenbruksprosjekter? Bruker dere noen digitale programvarer eller eksterne kartleggingsløsninger? (r.q.2)
- Kan du forklare hvordan disse metodene fungerer i praksis i et "typisk" byggeprosjekt? (r.q.2)
- Fra ditt perspektiv i bransjen, hva mener du er vår største utfordring når det gjelder gjenbruk i byggeprosjekter? (r.q.3)
- Hvordan mener du at vi kan legge til rette for økt gjenbruk i bransjen? (r.q.3)

Regulering:

- Hva mener du må gjøres med regelverket for å kunne legge til rette for gjenbruk? (r.q.3)
- Hvordan forholder dere dere til reguleringer i bransjen, spesielt i forhold til BREEAM, Tek17 krav, FutureBuilt, og andre nye reguleringer eller anbefalinger som har kommet? Er det andre verdt å nevne? (r.q.1,2,3)

Digitalisering:

- Har din organisasjon fokus på digitalisering i prosjekter? (r.q.1,2,3)
- Hvis ja, hvordan blir dette implementert? (r.q.1,2,3)
- Hvordan mener du digitalisering kan fasilitere for økt gjenbruk? (r.q.1,2,3)

NTNU

Norwegian University of
Science and Technology