Master thesis

Master's Programme in Industrial Management and Innovation 120 credits

Barriers of circular economy transition for a construction firm

Thesis in Industrial Management and Innovation, 30 credits

Halmstad 15/06/2023
Felix Ahlström Jönsson
Erik Janson

HÖGSKOLAN I HALMSTAD

Abstract

The construction industry is one of the most resource-intensive industries in the world, therefore, scientists, the industry and governments are pushing for a transition to a Circular Economy (CE) within the industry to address this issue. This study explores the barriers to CE transition within the construction industry, examining how these barriers are perceived by practitioners and contrasting them with academic perspectives in the literature. The barriers identified in the literature were categorized via industrial transition theory based on the regime actors of the Multi-level perspective on transition framework by Geels & Schot (2007) and then aggregated via subcategories based on similarities in barrier definition presented in the literature. By interviewing 8 respondents, 28 barriers to CE transition were found within the categories and subcategories of data coding. The findings revealed that the industry is cautious about CE, which is impeding the drive for transition and affecting further perception and awareness of the concept. Furthermore, it is crucial to investigate barriers individually and how they are interconnected to others, as they collectively contribute to the low and slow progress of industrial transition toward CE in the construction industry.

Keywords: Circular economy, CE, Industrial transition, Life Cycle Assessment, Barriers, Circular construction, Circular transition

Preface

The topic of circular economy in the construction sector became almost a bit of an obsession for us after writing a structured literature review on the topic. The literature that we drew from the online literature databases Web of Science and Scopus after the recommendation of two experienced Professors within the field of construction management at Halmstad University is what inspired us to write on this topic and created a literature base that served as the basis for this thesis. So, we want to thank Halmstad University for providing us with the inspiration and tools necessary to conduct this thesis.

Special thanks to Anna-Maria at PEAB for supporting us every step of the way and being the contact person for all interactions with the firm, providing us with all the data needed. Thank you again for always having time to help us with questions, supplying us with resources and data, and supporting the thesis. Extended thanks go out to the people at PEAB who were able to take time out of their schedule to participate in interviews, we would have no thesis without your industry insight.

Big thanks goes out to our thesis supervisor Henrik Florén, who has been our main motivator and guiding hand but also our biggest critic when we needed harsh but firm constructive feedback. The thesis would have never been finished without your expertise, both within the world of academic writing and within the world of the construction industry.

We also want to thank our classmates, who have been a great source of friendship, support and inspiration during these last two years of our life and enabled us to develop our thesis further via their brilliant feedback.

Ultimately, this thesis would not have been possible without the unwavering support of our families and friends, so consequently we fully dedicate this thesis to you.

Halmstad, June 2023

Erik Jansson Felix Ahlström Jönsson

Table of Contents:

Table of figures:

1. Introduction

1.1 Background

As it stands today, the extraction and processing of resources produce half of the total greenhouse gas emissions and over 90% of biodiversity loss and water stress (Parliament, 2021). The construction industry is a typical case of this, as it is the most resource-intensive industry in the world and produces a third of the European Union's (EU) total waste, being responsible for 30% of the world's consumption of raw materials, 12% of its land, 25% of its water resources, and 40% of its energy consumption (Bilal et al., 2020). This makes it of high interest to increase material efficiency and reduce the industry's climate impact. To address these issues, a transition to a circular economy (CE) within the construction industry has been suggested by the industry, scientists, and governments (Hossain et al., 2020)

CE encourages the transition of a linear economy based on take-make-waste into one that focuses on three principles: eliminating waste and pollution, circulating material, and regenerating nature (Ellen MacArthur Foundation, 2021). Promoting any economic process or practices aiming at creating a regenerative and sustainable economic system via 'reduce, reuse, and recycle' in production, circulation, and consumption processes is described as a CE activity (Kirchherr et al., 2017). CE theory states that CE activities offer opportunities for increasing domestic product and employment possibilities while raising material supply and price resilience (Bilal et al., 2020; Korhonen et al., 2018).

There are many examples of CE activities being implemented in the construction industry. For example, the use of modular construction techniques, which allow for the reuse of building components, is becoming increasingly popular. Additionally, building materials made from recycled or upcycled materials are on the rise (Hossain et al., 2020). Adams et al. (2017) also describe that designing for deconstruction, adaptability, and flexibility at the end-of-life phase is a key enabler for CE. However, these

activities are a few of the lesser-studied parts of the CE in relation to the construction sector, even with the value chain implications (Antwi-Afari et al., 2021).

In addition, construction waste management has become increasingly important due to harsher sustainability requirements, disposal and landfill regulations, and lower availability of landfill capacity (Rios et al., 2015). This has led the EU to designate the construction sector as a priority area for the CE transition to achieve global sustainability goals, such as Agenda 2030 (Regeringskansliet, 2023). EU´s strategies to enable CE include revising the construction product regulation, promoting CE principles for building designs, and integrating life cycle assessment (LCA) in public procurement (Parliament, 2023).
However, despite this priority, the transition has been low and slow (Giorgi et al., 2022; Zandee et al., 2022).

The transition from a linear take-make-waste model to a circular model represents an industrial transition (Chizaryfard, 2023). Geels and Schot's (2007) multi-level perspective (MLP) framework provides an understanding of this transition. It encompasses various dimensions of the sector, including the market, industry, policy, science, technology, and culture. During an industrial transition, existing regimes within the sector are disrupted, leading to operational challenges that must be addressed. These challenges have contributed to the slow and limited progress of the construction industry in transitioning toward CE.

Many firms face difficulties in reusing existing resources and capabilities to provide new forms of value to survive in a rapidly changing globalized business environment (Bigelow & Barney, 2020). This difficulty is further emphasized in the construction industry due to limited space in construction sites and the industry's resource insensitivity (Bilal et al., 2020; Nasir et al., 2017). Additionally, the construction industry is a project-based industry where most construction projects are unique, making it difficult to find holistic value chain solutions (Chen et al., 2022).

Overall, the implementation of CE activities in the construction industry has the potential to significantly reduce the industry's environmental impact while also improving economic efficiency and creating new job opportunities (Akinade & Oyedele, 2019; Giorgi et al., 2022).

1.2 Problem discussion

Despite the increased interest, the CE concept entails a transformative shift in the socio-technical landscape spurred by societal pressures rather than a singular innovation. Regime actors, who are the ones that affect the markets, industry, policy, technology, science, and culture, can be compelled to adapt due to such societal pressures by adjusting their developmental trajectories and innovation practices (Geels & Schot, 2007).

The regime actors might constrain the pace and magnitude of a transformation if there is a reluctance to respond to these pressures or by the limited impact of cumulative adjustments and reorientations (Geels & Schot, 2007) The reluctance from regime actors is related to a number of general challenges, such as significant sunk-cost investments into machines, infrastructure, and competencies that act as barriers to the transition of CE (Geels & Schot, 2007).

Within the construction industry context, the transition of the socio-technical landscape to CE is taking form as a push from the construction industry, governmental actors, researchers, and societal actors to facilitate more sustainable construction (Hossain et al., 2020). Additionally, there are challenges specific to the construction industry relating to the transition to CE, such as the fragmented nature of the supply chains, where the construction of a building requires a complex net of actors and suppliers while being exposed and vulnerable to strict regulations (Chen et al., 2022).

Despite the push, practitioners within the construction industry do not fully understand how transition to CE can become financially profitable,

becoming a knowledge gap that is creating barriers for CE transition (Adams et al., 2017; Bates, 2022).

To facilitate the transition to CE, there's a need to identify the barriers and unearth potential enablers (Shooshtarian et al., 2022). CE activities remain largely unexplored within the emerging CE literature, leaving practitioners unsure of how to implement circularity and what demands need to be placed from the start in a project development position (Hossain et al., 2020). This creates a research gap to understand empirically what barriers exist for companies before adopting such a circular activity. This can lead to an increased understanding of how CE activities can facilitate a circular transition, as most CE activities are connected (Goteborg Stad, 2021).

1.3 Purpose

The aim of this thesis is to provide a better understanding of what is impeding the transition to a circular economy within a single construction firm via the exploration of barriers.

1.4 Research question

RQ: What barriers hinder the circular economy transition in a construction firm?

2. Theoretical framework

The chapter provides a theoretical background to key terms and key concepts used for the duration of the study. It provides an overview of the Industrial transition and CE concept, the potential implications of CE in the construction industry, and the theoretical barriers of CE activities in the construction industry. Barriers are then aggregated into a figure that categorizes CE barriers identified in construction sector literature based on regime actors of industrial transition and are then further subcategorized by similarities (Figure 3).

2.1 Industrial Transition

Geels and Schot (2007) define an industrial transition as a shift from one socio-technical regime to another, which stabilizes industry trajectories by providing a framework for engineers, regulations, and standards. It also involves adapting lifestyles to technical systems and significant investments into machines, infrastructure, and competencies that have become sunk costs.

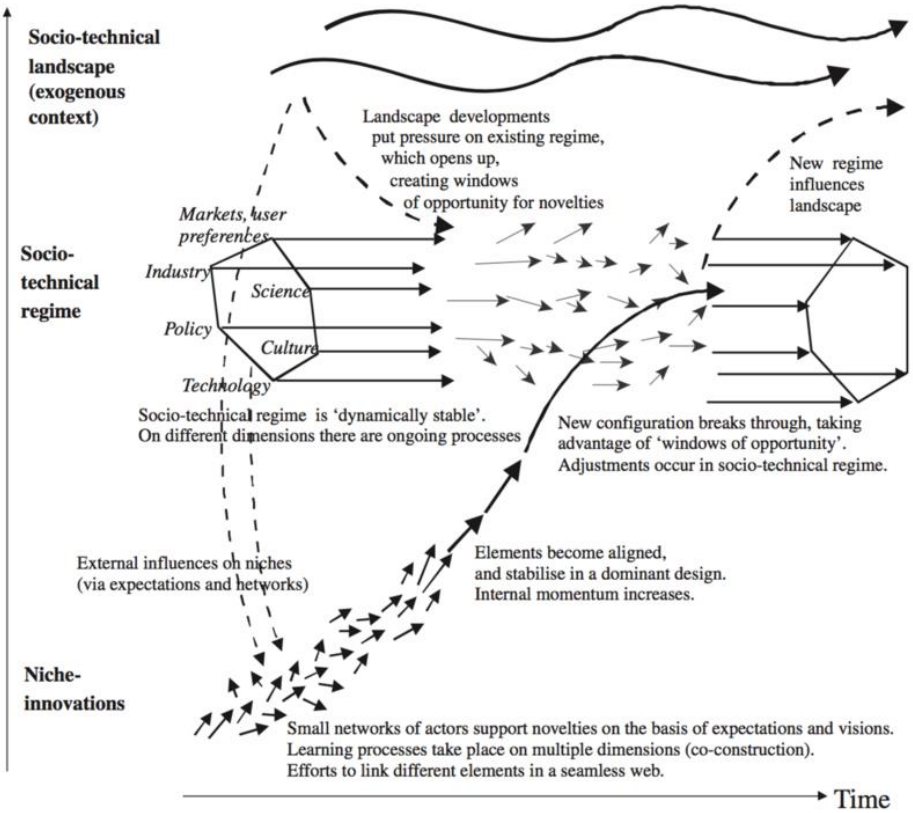

Figure 1: Multi-level perspective on transitions (adapted from Geels & Schot (2007), p. 401.

Multi-level perspective on transition framework by, Geels & Schot (2007) argues that a transition occurs in a multi-level perspective with the interaction between three levels: micro, macro, and meso (Figure 1). For example, a niche innovation (micro) builds momentum through improved price or performance, changing the sociotechnical landscape (macro), which is destabilizing the current regime (meso), and creating windows of opportunity for niche innovation (Geels & Schot., 2007). Allowing new inventions to become novelties, expand in the mainstream market, and compete with existing regimes.

An industrial transition is then brought about by waves of innovations, which shape and transform the economy and reshape society (Chizaryfard, 2023). This interferes with a current dynamically stable socio-technical regime that integrates markets (user preferences), industry, policy, science, technology, and culture by combining these elements to create a system that adapts and evolves over time (Geels & Schot., 2007). However, according to Chizaryfard (2023), the various parts of the system develop at different rates, making it difficult to coordinate with each other, and it is difficult to change one socio-technical regime member without affecting the others in the system.

Within industrial transition theory, the factors influencing regime actors are described in the following table: (Geels, 2006; Geels, 2002; Geels & Schot, 2007)

Regime actor	**Factors**	**Affects**
Culture	Cultural beliefs and values, Cultural practices and norms.	The socio-technical regime, Culture factors both shape and are influenced by landscape developments.
Technical	Technical innovations, infrastructural requirements, technological lock-ins, scalability, feasibility and the interaction between technologies.	Creation of tools and solutions.
Market	Market demand, market competition, economic incentives, support systems, market networks and interactions.	Shaping market demand and supply.
Science	Knowledge, research, and scientific understanding	Knowledge, research, and scientific

	of concepts.	understanding that contribute to a transition.
Policy	Regulatory frameworks, supportive policy instruments, standards and certification, sector-specific policies, international agreements, and public procurements.	Alignment and coherence of policy actors at different levels of governance.
Industry	Technological Innovation, Industry Networks, Value Chains, and Organizational Leadership.	Industry strategies, investments, and practices essential for driving an industrial transition.

Table 1: Regime actors and affecting factors.

Geels and Schot (2007) argue that the various actors involved in the current industrial system are resistant to change because they have invested a lot of time and money into the current way of doing things. Moreover, the different actors in the system are interconnected, meaning that any attempt to introduce new changes will have ripple effects throughout the system, requiring experimentation and adjustments in order to establish a new way of doing things (Chizaryfard, 2023).

2.1.1 Circular economy transition

CE has been seen as a transformative approach to today's problems related to climate change and the depletion of natural resources, which is a typical example of a socio-technical landscape change (Chizaryfard, 2023). Aiming to replace the current linear industrial model of take-make-waste with a cyclical model (Korhonen et al., 2018). This involves minimizing material consumption and creating effective management solutions for end-of-life products (Chizaryfard, 2023).

A CE transition is, however, not a typical transition. Since the push for CE comes from the socio-technical landscape rather than a niche innovation is called a transformation, where a niche innovation has not yet been sufficiently developed (Geels & Schot., 2007). Chizaryfard (2023) argues that the transformation to a CE requires radical changes to business models, technologies, infrastructure, and so on. In order to respond to a transition to CE, actors need to adjust their direction of the development path toward CE (Geels & Schot., 2007). While simultaneously adopting symbiotic niche

innovations and processes that aligned with the principles of CE (Geels & Schot., 2007).

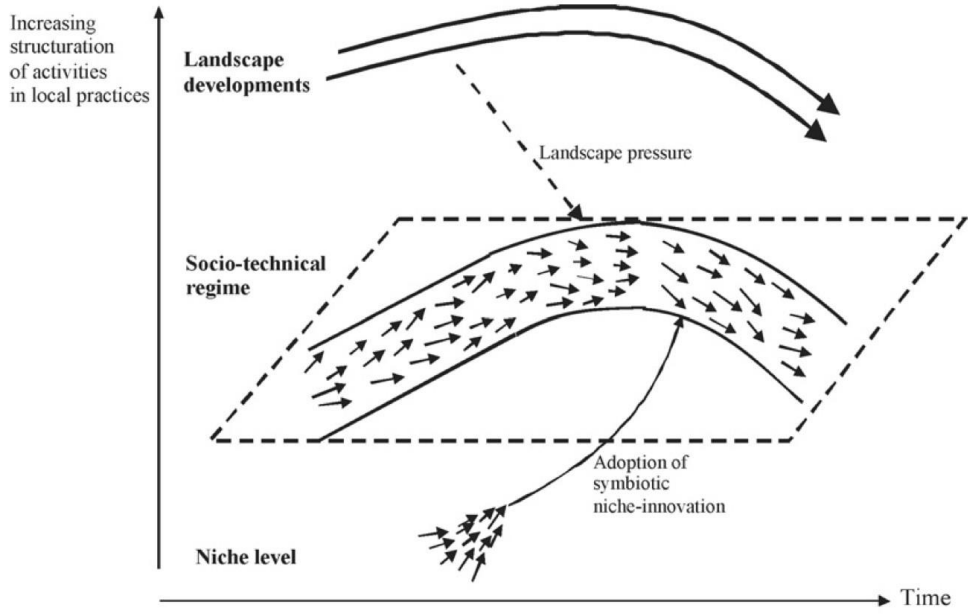

Figure 2: Transformation pathway, adapted from Geels & Schot (2007), p.407

Geels & Schot (2007) suggest that for the pressure from the landscape to be effective, the regime actors must perceive and act upon it. However, the implementation of a circular industrial system cannot be achieved by a single actor's efforts alone (Chizaryfard, 2023). The change will be driven by various factors, including conflicts, power struggles, and social-institutional factors, that reinforce the pressure put on the socio-technical regimes (Geels & Schot, 2007). The emergence of new regimes will occur through cumulative adjustments and reorientations from the old regimes (Geels & Schot, 2007).

A transition towards a CE in the construction industry is a socio-technical phenomenon that relies on adopting innovative methods and technologies (Adabre et al., 2022). While a circular industrial transition cannot fully be achieved by a single actor's efforts, there's a need for cooperation between multiple stakeholders, and regulations and incentives act as core implementation tools (Geissdoerfer et al., 2017). Therefore, Giorgi et al.

(2022) suggest that for a successful transition to start happening, construction firms need to promote tangible technologies. Technologies such as reversibility in production, and intangible technologies, which act as enabling tools, including digital technologies. Additionally, there must be stable value chain relationships for new circular business models in a win-win solution (Giorgi et al., 2022). As well as for a CE transition to be achieved, it needs to become a business goal (Shooshtarian et al., 2022). At the same time, needed to be supported by policy evolutions toward sustainable development, with the aim of realizing economic, social, and environmental goals (Adabre et al., 2022).

2.2 Circular economy

The most prominent definition of CE, as presented by Kirchherr et al. (2017), is: "an economic system that replaces the ‘end-of-life ’ concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes. With the aim to accomplish sustainable development, thus simultaneously creating environmental quality, economic prosperity, and social equity, to the benefit of current and future generations.”.

The CE concept introduces a sustainable alternative to the linear economy system, where income increase often leads to a rise in material utilization, waste generation, greenhouse gas emissions, loss of biodiversity, strain on water resources, and air pollution (Flack et al., 2023). In comparison, CE aims to decouple economic growth from environmental degradation (Korhonen et al., 2018). Which is normally achieved by implementing governance policies that promote and prioritize progress decoupled from material consumption (Velenturf & Purnell, 2021).

CE emphasizes closed-loop production systems, with a focus on the reuse and recycling of resources, energy efficiency, and refurbishing and repair rather than disposal (Korhonen et al., 2018; Mhatre et al., 2021). A closed-loop system retains products and materials by reintroducing them into the

system, creating environmental benefits by reducing the usage of primary materials and their associated environmental impacts (Hossain et al., 2020; Mhatre et al., 2021). While, at the same time, creating additional benefits and opening additional revenue streams by stimulating new business opportunities (Korhonen et al., 2018). Examples of this include material cost reduction via the usage of recycled materials, the sourcing of which requires additional manpower and thus creates jobs (Bilal et al., 2020; Korhonen et al., 2018).

However, CE has implications for the entire value chain, which can create partner restrictions (Giorgi et al., 2022; Linder & Williander, 2017). This requires understanding and incentives to be built with key partners such as contractors and stakeholders to maintain compatibility with current partners (Linder & Williander, 2017).

Furthermore, the broader implication of adopting CE principles is the improved use of sustainable materials by promoting material efficiency through recycling and reusing (Hossain et al., 2020). Hossain et al. (2020) state that sustainable sourcing of materials should be at the core of CE, as it may significantly influence the environmental impact depending on the ability to reuse or recycle the material. An opportunity to create a competitive advantage can be seen by increasing the productivity of resources that are currently underexploited and may be a source of possible future wealth and job creation (Mhatre et al., 2021).

2.2.1 CE implications in the construction industry

Globally the use of materials resources is rising, coupled with an increase in population and income (Hossain et al., 2020). Transition to CE in the construction industry can enable a successful transition to sustainable construction (Hossain et al., 2020). The starting point for transitioning to a circular construction industry is by understanding the various functions involved in the construction supply chain throughout the entire project lifecycle (Chen et al., 2022). Which involves the use of materials, products,

and construction practices that are both environmentally sustainable and promote efficient use of resources.

CE in the construction industry needs to focus on three approaches: slowing, closing, and narrowing the construction resource loops (Chen et al., 2022). This is done by reducing resource utilization by increasing the lifespan of buildings, preventing end-of-life building materials from being disposed of in landfills, and enhancing construction and design efficiency, thereby narrowing resource usage (Chen et al., 2022). By following these approaches, construction companies can reduce their waste by either minimizing or closing the loop and promoting resource efficiency of material by increasing the lifespan of buildings (Hossain et al., 2020; Korhonen et al., 2018; Mhatre et al., 2021).

Furthermore, CE can improve the value chain's resilience by developing regional alternatives to material or energy resources (Flack et al., 2023). While simultaneously reducing the dependency on global value chains reduces transportation costs and emissions and the risk of disruption due to geopolitical crises (Flack et al., 2023).

Effective transition to CE requires in-depth teamwork, consultation between project teams from the conceptual stages to demolition, and good leadership skills (Hossain et al., 2020). As well as for management to address the low acceptance of ideas and circular business models (Hossain et al., 2020; Mhatre et al., 2021). Mhatre (2021) argues that building information modeling (BIM) can unlock the potential of CE, where it can be used as a planning tool between the different construction phases, improving resource efficiency and helping value what material can be reused or recycled. Since improper evaluation and information management of a CE model influences the performance of circular activities (Ismail 2022).

2.2.3 Construction sector transition: Barriers

CE principles in the construction sector have been in its infancy stage for multiple years due to the multiple barriers and challenges surrounding potential transition (Adams et al., 2017; Giorgi et al., 2022; Zandee et al., 2022). Therefore, the first step is to understand the perceived barriers of transitioning to CE (Shooshtarian et al., 2022).

Within the most highly cited articles featured in ABS-chartered journals (Table 1) regarding CE in the construction sector, several barriers are presented. Barriers such as consumer short-termism, government policies and regulations, and lack of technologies (Adabre et al., 2022; Ghufran et al., 2022). Hossain et al. (2020) specifically mention some of the largest challenges of CE transition: economic uncertainty, constant supply and business risk, lack of tools and guidelines for the design of circular products and buildings, and the uncertainty related to reusing materials after their end-of-life. There are additionally key issues for CE in the supply chains, which are described to be barriers such as lack of incentives for actors towards circularity, lack of mutual interests among the supply chain actors, high uncertainties, and risks of consistent supply (Hossain et al., 2020).

Author and title:	Empirical setting	Categories	Key findings
Adams et al., 2017: Circular economy in construction: current awareness, challenges and enablers	Industry wide survey and a follow-up workshop	Technology Markets Culture Industry	The absence of incentives to design products and buildings for disassembly and reuse at the end of life is a significant challenge. To encourage greater implementation of circular economy principles throughout the supply chain, a clear economic case is paramount, supported by metrics, tools and guidance.
Akinade & Oyedele, 2019: Integrating construction supply chains within a circular economy: An ANFIS-based waste analytics system (A-WAS)	Experimental and case study research on the programming environment of a construction waste model.	Technology Science	The results of the study show that the (BIM) tool offers useful insights into Construction waste minimization opportunities.

Andersson & Buser, 2022: From waste to resource management? Construction and demolition waste management through the lens of institutional work	The field of CDW in the region of West Sweden. Interviews with several organizations and contractors across the industry.	Markets Science Policy Culture Industry	Although the work performed legitimizes CE principles and enables new initiatives, it mostly fails to change normative associations and to define new rules of action that support CE.
Bilal et al., 2020: Current state and barriers to the circular economy in the building sector: Towards a mitigation framework	Literature review on building sector literature on developing countries.	Markets Science Policy	A lack of environmental regulations and laws is driving the rest of the barriers to the circular economy. Equally critical is the lack of public awareness and support from public institutions.
Chen et al., 2022: Revamping construction supply chain processes with circular economy strategies: A systematic literature review	Systematic review on construction circularity literature	Markets Science Policy Culture Industry	The review revealed that the BIM-based and LCA-based methods have been widely used (in the construction industry); however, logistics network optimization to allow industrial symbiosis was not adequately addressed in the existing literature.
Çimen, 2021: Construction and built environment in circular economy: A comprehensive literature review	State of the art literature review on CE related to construction	Markets Science Culture Technology	CBECE literature remains at an early stage despite recent growth in academic interest. 90% of CBECE literature was published between 2017 and 2020 with subject diversity increasing over the years. A substantial portion of the literature was conducted in China and published by the Journal of Cleaner Production
Giorgi et al., 2022: Drivers and barriers towards circular economy in the building sector: Stakeholder interviews and analysis of five European countries policies and practices	38 interviews with stakeholders from across the construction industry in Belgium (Flanders), the Netherlands, Denmark, Italy, and the United Kingdom.	Technology Policy Culture	The results highlight the different and fragmented circular strategies currently applied in the countries analyzed, highlighting the need for more effective and coordinated actions and policies promoted by the European Commission. In particular, the current legislative framework promotes the waste management strategies, focusing more on recycling practices than on reuse or resource management.The researchers suggest that all circularity initiatives should undergo life cycle sustainability assessments to ensure they are achieving the desired goals

Hossain et al., 2020: Circular economy and the construction industry: Existing trends, challenges and prospective framework for sustainable construction	Systematic literature review of CE lin the construction industry	Technology Markets Science Policy Culture Industry	The study found that CE implementation into the case-specific building with full scale evaluation is yet to be conducted, and a comprehensive CE integration and methodology framework is yet to be developed.
Nasir et al., 2017: Comparing linear and circular supply chains: A case study from the construction industry	Case study focusing on two insulation products that compete in the same market segment, one made from circularity, one linearly.	Technology Markets Science	An integration of circular economy principles within sustainable supply chain management can provide clear advantages from an environmental point of view despite some external supply chain influences and scenarios.
Mahpour, 2018: Prioritizing barriers to adopt circular economy in construction and demolition waste management	Literature review of CE literature	Technology Policy Industry	In behavioral, technical, and legal perspectives, using finitely recyclable construction materials; ineffective C&D wastes dismantling, sorting, transporting, and recovering processes; and using finitely recyclable construction materials are the biggest barriers to CE
Shooshtarian et al., 2022: Circular economy in the Australian AEC industry: investigation of barriers and enablers	Surveys from several australian firms and stakeholders within architecture, engineering and construction industries	Markets Science Policy Industry	The top three barriers to CE were :'lack of incentives';'lack of specific regulations'; and a lack of knowledge'. The three top enablers were reported to be R&D of enabling technologies','educate project stakeholders and provide evidence for the added value'.

Table 2:Sources of CE Barriers presented in literature.

According to Chen et al., (2022), one of the biggest barriers to CE in the construction industry is due to the result of the fragmented value chains and resource-intensive production processes. However, the addition of new players, such as demolition contractors and recycling plants, in a circular construction value chain magnifies these challenges (Chen et al., 2022). Additionally, transition to CE faces multiple challenges, such as the

fragmented structure of the industry, the short-termism of clients/developers, the project-based nature of the industry, and the lack of collaboration across the supply chain pose significant obstacles to the implementation of CE, principles (Adams et al., 2017; Chen et al., 2022).

Shooshtarian et al. (2022) identify three separate barriers that are the key reasons for the low and slow transition of CE principles. They are inadequate knowledge, lack of capital, and uncertainty about the return on investments for organizations. Additional barriers described are the lack of legal warranties on recycled or reused materials and the lack of demand from the market, which hinders the successful implementation of CE strategies in construction (Chen et al., 2022).

Moreover, there is a lack of focus on the economic return of CE, as opposed to the environmental benefits, which presents a barrier for companies (Bilal et al., 2020; Hossain et al., 2020; Mhatre et al., 2021)
There are also technical challenges to the transition to CE, such as how to design buildings, components, and products for circularity (Adams et al., 2017). To overcome these barriers, various drivers are needed across the regime actors to influence and push for a transition (Adabre et al., 2022).

All the barriers presented in the construction industry literature of ‘’Table 2: Sources of CE Barriers presented in literature’’ are categorized in ‘’Figure 3: Barriers to CE according to construction sector literature, categorized by regime actors and aggregated by subcategorization of literature similarities.’’.

Technology

Material:

- Existing building stock that has not been designed for circularity (Adams et al., 2017)
- Other design challenges include the durability of recycled materials (Hossain et al., 2020).
- Achieving efficiency in material flow (Akinade & Oyedele, 2019)
- Using finitely recyclable construction materials (Mahpour, 2018)

Tools and processes:

- Lack of tools and guidelines for the design of circular products and buildings (Hossain et al., 2020).
- Lack of a standardized information system about an international resource bank (Çimen, 2021).
- The lack of market mechanisms to promote materials recovery and an ineffective process chain for recovering (Giorgi et al., 2022).
- Ineffective C&D wastes dismantling, sorting, transporting, and recovering processes (Mahpour, 2018)

Complexity

- Complexity of the supply chain (Nasir et al., 2017)
- Challenges such as tracking material stock and flow (Çimen, 2021).
- Geographical differences (Nasir et al., 2017)
- Project complexity (Akinade & Oyedele, 2019)

Markets

Uncertainty:

- Lack of unproven business cases underpinned by viable business models (Adams et al., 2017).
- Unclear financial case (Adams et al., 2017)(Hossain et al., 2020).(Shooshtarian et al., 2022)(Çimen, 2021).(Andersson & Buser, 2022)
- Uncertainty about the return on investments (Shooshtarian et al., 2022)
- Economic uncertainty (Hossain et al., 2020).
- high uncertainties and risks of a consistent supply of recycled material (Hossain et al., 2020).

Financial:

- Today, prices are low, making it uneconomical to reuse (Adams et al., 2017).
- Low value of many construction products at the end of life (Adams et al., 2017).
- Inadequate financial resources (Bilal et al., 2020).(Shooshtarian et al., 2022)
- Lack of demand from the market brings additional hurdles (Chen et al., 2022).
- Lack of financial incentives (Chen et al., 2022; Shooshtarian et al., 2022)

Culture

Interest:

- Stakeholder challenges (Çimen, 2021).
- Lack of mutual interest among supply chain actors (Hossain et al., 2020).
- Absence of managers' commitment (Andersson & Buser, 2022)
- The lack of political priority (Giorgi et al., 2022).
- Scarce interest and demand from clients (Andersson & Buser, 2022)

Attitude:

- Negative attitudes toward reuse practices (Andersson & Buser, 2022)
- Lack of agreement causes a considerable amount of rework and waste (Chen et al., 2022).
- Short-term thinking (Adams et al., 2017).
- The social dimension of construction (Çimen, 2021)
- The conservativeness of the building industry (Giorgi et al., 2022).

Science

lack of Information:

- Lack of public awareness and support from public institutions (Bilal et al., 2020).(Çimen, 2021).
- Lack of knowledge (Shooshtarian et al., 2022)(Çimen, 2021).
- Uncertainty related to reusing material after their end-of-life (Hossain et al., 2020).

Information diffusion

- Data fragmentation between stakeholders (Chen et al., 2022). (Nasir et al., 2017),
- Lack of information transparency (Chen et al., 2022).
- Lack of information across the supply chain (Shooshtarian et al., 2022)(Hossain et al., 2020)(Akinade & Oyedele, 2019)(Çimen, 2021).
- Lack of training (Andersson & Buser, 2022)

Policy

Regulations:

- Lack of environmental regulations and laws is driving the rest of the barriers to the circular economy (Bilal et al., 2020).(Shooshtarian et al., 2022)(Giorgi et al., 2022).(Andersson & Buser, 2022)
- lack of specific regulations (Shooshtarian et al., 2022)(Giorgi et al., 2022).(Andersson & Buser, 2022)
- absence of European coordination of policies for construction waste management (Giorgi et al., 2022).

Ownership:

- Agency and ownership issues of the end-of-life of materials (Hossain et al., 2020).(Shooshtarian et al., 2022)(Giorgi et al., 2022).(Andersson & Buser, 2022)
- Lack of legal warranties on recycled or reused materials (Chen et al., 2022).(Shooshtarian et al., 2022)(Giorgi et al., 2022).(Andersson & Buser, 2022)
- ineffective contract forms (Andersson & Buser, 2022)
- agency and ownership issues in C&D waste management (Mahpour, 2018)

Industry

Integration

- Inadequate communication with clients, designers and subcontractors (Hossain et al., 2020).
- Fragmented value chain (Chen et al., 2022).
- Lack of leadership skills (Hossain et al., 2020).
- Lack of integration of sustainable waste management and potential reuse (Hossain et al., 2020).
- lack of integration of sustainable C&D waste management (Mahpour, 2018)
- Lack of a holistic approach across the supply chain (Adams et al., 2017).

Incentives:

- Lack of incentives for actors in a supply chain to adopt CE (Hossain et al., 2020).
- Lack of public incentives (Andersson & Buser, 2022)
- Lack of incentives to use recycled materials (Hossain et al., 2020).(Adams et al., 2017).(Shooshtarian et al., 2022)

Risks and uncertainty:

- Uncertain aftermaths of moving toward circular economy in C&D waste management (Mahpour, 2018)
- Associated uncertainty in C&D waste management (Hossain et al., 2020).
- Supply and business risk (Hossain et al., 2020).(Shooshtarian et al., 2022)
- Shortage of space and information on site (Andersson & Buser, 2022)

Figure 3: Barriers to CE according to construction sector literature, categorized by regime actors and aggregated by subcategorization of literature similarities.

2.3 Circular activities in construction:

There are many activities that can be conducted in a construction context that can be considered to facilitate sustainable or circular construction.

2.3.1 Life cycle assessment

The construction sector is currently looking towards Life cycle assessment (LCA) methods as an objective way of evaluating the environmental impact of construction practices as a response to the current push towards sustainable construction (Singh et al., 2011).

Within the construction sector, traditional LCA methods are used for assessing the life cycles of buildings, starting from the usage of virgin materials and material extraction and processing (Xue et al., 2021). LCA methods are additionally used to facilitate the design process by identifying the largest environmental impact reduction opportunities throughout a building's life cycle. This means that LCA methods assist in material selection via sustainable material sourcing and can be used to predict the environmental performance of buildings whilst assisting sustainable decision making (Xue et al., 2021). LCA is additionally connected to design for deconstruction principles in order to analyze the environmental impact savings resulting from the reuse of construction elements (Eberhardt et al., 2022).

LCA is an analytic tool used for assessing product development processes from the start-of-life to end-of-life of their life cycles (Singh et al., 2011). For these purposes, the LCA tool takes several aspects into consideration such as the natural environment, human health and resource depletion, this in combination with the life cycle perspective LCA prevents problem-shifting between different life cycle stages (Buyle et al., 2013; Finkbeiner et

al., 2006).

One of the major strengths of an LCA approach is that it defines products and processes based on their function and perceived benefits rather than their specific physical characteristics. This allows for a frame of comparison between products which are inherently different but fill similar functions and provide similar benefits, such as different types of construction materials such as wood or concrete (Finkbeiner et al., 2006; Guinee, 2002, p. 4).

LCA methods have been part of numerous scientific efforts promoting sustainability efforts (Xue et al., 2021). And according to Xue et al., (2021) An integrated framework for CE transition with a Building information (BIM)-based LCA can promote sustainable and circular construction. Pomponi & Moncaster, (2017) additionally suggest that LCA can be integrated to enable effective implementation of CE activities if it has support from supplementary design tools such as BIM. However, even with the numerous studies relating to LCA integration for supporting CE transition, the main focus of LCA application has been on project design rather than on refurbishment and demolition (Fořt & Černý, 2020).

There exist complications in conducting LCA in the construction of buildings due to the complexity and time consuming nature of collecting necessary data and information (Zabalza Bribián et al., 2009). Additionally, LCA's are traditionally conducted towards the end of the design processes within the construction sector, which impact LCAs potential as a decision making tool, due to changes at that point in the process might be too difficult, time consuming and costly. (Cavalliere et al., 2019). Thus the selection of sustainable materials must be made as early a possible during the design, which is being increasingly adopted in the building design process (Xue et al., 2021)

2.3.2 Design for deconstruction

The concept of design for deconstruction describes the process of dismantling a building to salvage its materials for future reuse or recycling is determined at the start of the building's life cycle. This can be an important process to strategy to conserve construction materials (Rios et al., 2015). This process requires changes to the normal construction methods, processes and planning which are acting as barriers to implementation.

For implementation of design for deconstruction it is important to consider the durability and longevity of materials, the ease of disassembly and access to valuable components, minimizing the use of adhesives and other materials that make disassembly difficult, design for flexibility and adaptability, and design with the whole life-cycle of the building in mind (Eberhardt et al., 2022).

Designing for deconstruction has many opportunities and constraints which lead to value chain implications. The opportunities include reduction in landfill debris, increased economic activity based on reuse of materials, easier management of hazardous materials and less noise than standard demolition. While the constraints include: larger time investment, lack of supply-demand mechanisms from the market, lack of standards and guarantees on certain material and storage issues (Cai & Waldmann, 2019).

The current re-emergence of the design for deconstruction concept stems from one of the key principles of CE, waste management increasingly becoming a concern within the construction industry where construction and demolition waste represents a third of all waste generated. In addition to this, demolition is responsible for 90% of all the construction and demolition waste (Bilal et al., 2020; Kibert, 2016).

Augenbroe & Pearce, (2000) described design for deconstruction as a future challenge of the construction industry as there is a need for adaptation in current design processes and material markets. In facing these challenges,

professionals and academics have described design professionals as having the most important role for facing the situation of facilitating deconstruction activities and material salvage. Therefore the development of the Design for deconstruction concept is heavily dependent on design professionals to close or narrow construction material loops (Kibert, 2016; Liu, 2009; Srour et al., 2012; Webster et al., 2005).

2.3.3 Recycling market & Material bank

In order to effectively manage recycling and direct use of materials and components obtained via deconstruction of old constructions, the concept of "material banks" have been proposed to facilitate material recycling and component reuse, both of which have CE implications (Cai & Waldmann, 2019).

There is a need for infrastructure that supports the dismantling, reconditioning, and sales of used building materials, as well as the responsibility of product and material manufacturers to develop recycling processes. By creating a secondhand market via creation of material banks, a usage of reusable materials can be facilitated rather than consumption of newly produced construction materials, leading to potential waste (Velenturf & Purnell, 2021).

A material inventory is an important step towards achieving circularity in construction projects, as it allows for the identification of materials that can be reused and recycled. To support this, improved information management is necessary, including the development of tools and regulations for storing and managing information about building components. Feasibility studies and training in material inventories are also important, as is the classification of materials according to reusability. Finally, the results of material inventories need to be connected to digital databases to support project planning and management. Overall, continued development in these areas is essential for advancing circular construction practices. These are potential functions a material bank can be used for (Cai & Waldmann,

2019).

To establish a market for reuse, demand and supply need to increase at a relatively even rate, and large-scale public procurement can be an effective tool to speed up development in the area. The establishment of recycling consultants can help coordinate product flows, and certification systems or reasonable guarantees for recycled goods need to be established. Additionally, warranty requirements for developers need to be adapted to recycled products, and risks associated with recycled materials need to be managed, such as conflicts between chemical legislation and recycling (Goteborg stad, 2020). There are additional complexities in the supply and demand of reusable materials however, considering that the supply is based on how much is deconstructed from buildings marked for demolition. This creates a hard capacity of available materials and also limits the potential material types available for reuse (Chen et al., 2022).

The importance of storing information about built-in products and materials in a digital database to increase circularity in construction projects. The information should be integrated into the entire chain from production through decommissioning and dismantling. There is a need to develop economic models for information storage, regulations or industry agreements on how to manage and store information, tools for storing and updating information, and database models for public access to information about products and their material composition. All of these developments would help increase the potential for using buildings as material banks in new projects and increase the possibility of planning and projecting to use construction products to be dismantled from other projects (Goteborg stad, 2020).

3. Method

To answer the research question of the thesis, the study is using an explorative, qualitative case study approach with a data structure to facilitate the analysis.

The qualitative case study will include interviews of members across the value chain at the Swedish construction sector firm PEAB and observations of a project team at PEAB working with implementation of standardized LCA calculations across the firm for sustainability reporting purposes, which is one of the major ways the construction industry is currently working with CE (Velenturf & Purnell, 2021).

3.1 Case description

PEAB is one of the largest actors in the Nordic construction sector, with 130 offices spread across Sweden, Denmark, Finland and Norway. PEAB was founded in Sweden 1959, but did not start working with construction contracting until 1970 and has since 2003 worked exclusively within the construction, civil engineering, industry and project development business areas. However, PEAB is by proxy active within other business areas via its subsidiaries Swerock, PEAB Asfalt, Lambertsson, Swecem, Byggelement and Smidmek. This means that PEABs business areas also include Mineral Aggregates, Paving, Concrete, Transportation and Machines, Rentals and Construction Systems (*PEAB Annual Report*, 2022).

Since 2022-01-22 Peab reportedly has 9 188 employees and an annual revenue of 40 152 billion SEK in Sweden alone, this marks PEAB as the largest actor in the Swedish construction sector (*PEAB Annual Report*, 2022). These qualities are the main reasons why PEAB was chosen as the empirical setting. PEABs status as the largest actor in the Swedish construction industry will allow the authors wider data access, as there are more possibilities for observation and potential respondents.

The authors are working in close contact with the regional PEAB headquarters in Mölndal, Gothenburg Sweden but had interviews with employees from other offices across the firm.

The office in Mölndal is primarily concerned with client relations and the construction design phase of buildings, this allows the authors to more closely observe how PEAB is working with circularity in early steps of construction. This additionally enables the authors to work with a snowball approach to data collection, starting upstream and working downstream.

The size of the firm has potential implications in the transferability and generalizability of the findings. The generalizability of findings might be limited however, as smaller firms might not experience the same barriers in the same way a large firm as PEAB do. However, due to the size of the firm and therefore being representative of the larger Swedish construction sector, the barriers found must have some form of transferability to other construction firms.

PEAB places large emphasis on a 2045 climate neutrality goal in their 2022 annual report, and for these purposes PEAB is currently working with several projects related to the transition to green and sustainable construction (*PEAB Annual Report*, 2022). This makes PEAB interesting to observe as they are a major player pushing for transition to sustainable construction. One specific project of great importance for the study is the implementation of Life cycle assessment calculations in the sustainability reporting because life cycle assessment is a method heavily tied to circularity, a project which the authors were able to be active participants in (Pomponi & Moncaster, 2017; Xue et al., 2021).

An additional reason why PEAB is interesting to observe is due to their work and 50% ownership of the Varvsstaden project in Malmö, Sweden. Varvsstaden is a construction project which works with deconstruction of the nearby shipbuilding yard ‘’blåa hallen’’ for the purpose of sourcing steel, brick, glass, wood and 10.000 square meters of reinforced concrete to

supply the project with construction material (Kärrholm, 2014, pp. 6–7). The Varvsstaden project is one of the most prolific cases of construction material reuse and deconstruction in the Swedish construction sector. This makes PEAB increasingly interesting to examine, due to their active involvement within the project (Tornkvist, 2015). This makes it possible to reach individuals who are actively working with reuse of construction materials and capture their experiences in what challenges and barriers that entails.

PEAB is motivated to transition to CE practices, which motivates PEAB to have this study. The contact person at PEAB which enabled data access for the study stated that circularity is something that the industry is transitioning towards. However, it is additionally stated to be a concept in which there is lack of knowledge within the firm, further motivating PEAB to acquire this study. While this can be seen as a conflict of interest, the authors have no affiliation towards the firm and are solely motivated in mapping barriers to CE transition for educational purposes.

3.2 Qualitative case study

The qualitative case study is conducted in a semi-structured interview format supported by an interview guide (Appendix 1). The case study will additionally include observations on a project team at the Swedish construction firm PEAB working with the implementation of LCA calculations as a standardized way of calculating environmental impacts across the company. While the CE implications of LCA calculations are a relatively small part behind the motivations of implementing LCA calculations, LCA implementation has been stated by several authors to enable circularity in the construction industry (Parliament, 2021; Pomponi & Moncaster, 2017; Xue et al., 2021). Therefore, it is of great interest to observe how the construction industry works with LCA, for CE implications. Parallel to those observations, the authors were present at an industry seminar related to circular construction which are hosted by and for other actors in the construction industry.

As the study regarding the perception of barriers is an inherently subjective concept, it is therefore appropriate to conduct a qualitative study which enables investigative research on different perspectives, views and perceptions (Yin, 2015). Thus, the qualitative approach is a good fit for the study, since research of perspectives, views and perceptions are necessary in order to understand the barriers to CE transition in the construction sector.

The authors decided to use a single case study due to a desire to explore different interpretations and perspectives from industry experts across a single firm. PEAB is in a unique position due to its size, being one of the largest construction firms within the Swedish, Norwegian and Finish construction industry. Thus, the firm is largely representative of the Nordic construction sector due to its size.

By immersing into a single firm, the authors were able to gather perspectives from a wider variety of roles, rather than gathering data from similar roles across different firms, resulting in similar perspectives and viewpoints. This is further reflected in the construction CE literature in Table:1 all focusing on a meso level understanding of the barriers, rather than the micro level understanding of barriers by examining a single firm. Therefore, by analyzing a single firm, the authors contribute to a deeper understanding of barriers impeding the transition to CE and will result in answering the research question of the study.

3.2.1 Interviews

Interviews serve as the primary form of empirical data collection within the study. To capture perspective differences in the understanding of CE within the construction industry, the authors are interviewing internal PEAB members from the design phase of construction, the client side of construction such as project management and the construction site perspective. Due to the fragmented nature of the construction sector, it is important to capture perspectives from several internal members along the

value chain to have a picture of the current state of the construction industry (Chen et al., 2022). This will provide an understanding of what barriers are impeding the transition to CE in the construction sector, from several practitioner's perspectives.

For the sampling of potential respondents, the authors were working with a snowball approach, starting from the sustainability manager of project development for Region Väst at PEAB, which acted as a contact person and informal supervisor for the data collection at PEAB. This contact made it possible to set up interviews with several workers spread across different functions at the firm, which then snowballed into further interviews based on recommendations of initial respondents.

The authors found this an appropriate method of interview sampling, as snowball sampling allows organic sampling of actors within PEAB that are tangentially aware about CE agendas and pushes present within and outside the industry (Bell & Bryman, 2007). Thus, these individuals might be good sources of data collection, individuals which would have been difficult to identify in other ways due to the fragmented nature of the construction industry. This method was additionally a good way of building a wide network of contacts across the firm for broader data access, which might otherwise have been a challenge in an industry as fragmented as the construction sector (Chen et al., 2022).

The authors were specifically aiming for interviews with actors that are aware of the industrial push of CE from the construction sector. Getting the perspective of construction design workers was especially important as design workers are highlighted within CE literature as having a key role in enabling CE (Kibert, 2016; Liu, 2009; Srour et al., 2012; Webster et al., 2005).

The interviews were held in a semi-structured interview format in 30-60 minute long sessions, which were supported via a flexible interview guide. The semi-structured interview questions were adapted in accordance to who

was being interviewed resulting in different versions of the interview guide, all of which are found in the appendix (Appendix 1). The questions were kept general, to allow respondents freedom in how they expressed potential CE barriers. The semi-structured format allowed the respondents to go off-script and provide their personal opinions about the internal CE push and work culture, which could hide additional challenges, barriers and findings. To provide validity, all interviews were recorded and then transcribed via native Microsoft teams functions, the transcriptions and recordings were additionally used to serve as basis for the data collection and data analysis.

3.2.2 Respondent details

The content of the current section is aimed towards representing the participants of the data collection. Thus, a brief description of each respondent and their professional background in the construction sector is provided.

The first interview was with the sustainability manager of project development at PEAB. This individual was chosen due to their direct knowledge of how circularity is being diffused within the firm. This individual additionally has direct knowledge of where the push for CE and construction is coming from, which allowed the individual to serve as a direct informant and informal advisor. This individual presented several actors which could be interviewed for a broader understanding of the topic of circular construction, serving as a form of snowball sampling. This enables the gathering of perspectives which otherwise might not have been considered otherwise.

Interview #1: Sustainability manager project development

The first respondent is currently working as the Head of sustainability in project development for Region Väst at PEAB. The individual has worked at PEAB for around a year but has worked within the industry for ten years. They have an academic background in the science of sustainability and are currently involved in projects relating to sustainable construction, most notably the involvement of PEAB in a platform for climate neutral

construction, projects in circular construction and implementation of LCA methods in their sustainability reporting. The individual is currently active with the design side of construction.

Interview #2: Project manager

The second respondent is working from the client side of construction, providing a new perspective from the previous interview. This individual has been with PEAB for six years, working as the key project manager of Region Väst for two of them. The individual is primarily concerned with managing the juridical implications of larger construction projects within the firm.

Interview #3: Site manager

Respondent number three is active as a site manager for PEAB in Region Väst and has worked at PEAB for over 20 years. Main responsibilities at the construction site include keeping the timeline of production, economical responsibilities, working environment and follow-up of project completion. This individual provides a construction site perspective of circularity within the construction sector.

Interview #4: Project manager of infrastructure

The fourth respondent is active as a project manager of infrastructure for the Varvsstaden project in Malmö, which is 50% owned by PEAB. Varvsstaden is the most prolific and large-scale case of material reuse in Sweden and therefore the perspective of this individual is invaluable in identifying barriers related to CE as they have personally experienced them.

Interview #5: Group manager, energy and climate

Respondent number five has been active within PEAB since 2015 and has been within their current role since 2017. The respondent is active within the subsection PEAB Teknik, which is part of PEAB Bygg, PEABs largest business area. The respondents' main responsibilities lie in being the leader of a group of six individuals working with qualitative calculations for energy and climate business development purposes.

Interview #6: Energy specialist

This respondent is also a member of PEAB Teknik, the same as respondent #5. This respondents' main responsibilities lie in energy calculations and environmental certifications. Within those work responsibilities work consists 70% of project planning and 30% as an internal consultant. However due to requests from the firm, the respondents' responsibilities have started to include more sustainability aspects.

Interview #7 Head of sustainability

Respondent number seven is currently employed at PEAB as the nordic sustainability manager. Meaning that the respondent is managing the project development business area of PEAB, one of its main business areas. The respondent mostly works with long term sustainability projects but is also working with more short-term projects such as keeping important documents up to date and supplying the workforce with necessary education for work within the firm. The respondent is currently heading several sustainability projects within the firm, and most notably for this study also heading the LCA calculation project group.

Interview #8 Construction manager

This respondent is the Construction manager at PEAB Teknik. Their focus lies in managing construction projects, which provides valuable insights regarding what difficulties and challenges circularity might bring to traditional construction methods.

Respondent and title	**Work responsibilities**
#1: Sustainability manager project development	Projects relating to sustainable construction, active with the design side of construction.
#2: Project manager	Managing the juridical implications of larger construction projects within the firm.
#3: Site manager	Keeping the timeline of production, economical responsibilities, working environment and follow-up of project completion.
#4: Project manager of infrastructure	Project manager of infrastructure for the Varvsstaden project in Malmö.

#5: Group manager, energy and climate	Leader of a group of six individuals working with qualitative calculations for energy and climate business development purposes.
#6: Energy specialist	Energy calculations and environmental certifications.
#7 Head of sustainability	Managing long term sustainability projects, such as the LCA calculation project group.
#8 Construction manager	Managing construction projects.

Table 3:Respondent details

3.2.3 Observations

The construction sector is a primarily project driven industry, thus it is of great importance to observe how the construction sector works with CE activities from a project management perspective to discover and understand challenges (Vrijhoef, 2008).

For this purpose, the authors were involved as active observers in a PEAB project group working with the implementation of LCA calculations as a standardized way of calculating environmental impacts across the firm for sustainability purposes, which could have implications for CE transition. This enables a greater understanding of how the work with CE practices is currently being conducted in the construction sector.

The project group for LCA implementation in sustainability reporting was held in one-hour-long sessions once per month. The meetings included actors across several regions, as the project's end goal was the widespread implementation of LCA calculations across the firm.

The presented project description is as follows: Conduct LCA calculations for four construction projects in Sweden and one in Norway with SGBCs zeroCO2 as a starting point for how LCA calculations could be conducted within PEABs own projects. The timeframe of the project is the planning phase from 22-10/22 to 22-12/22, with the project phase running from 23-01/23 to 23/05-23, meaning that the authors were present for the entire duration of the project.

For inspiration on how to finish the project, PEAB will be looking at how the project development team in Finland is currently conducting their LCA calculations. Additionally, PEAB will be working with a consultancy group for support in the implementation of the LCA calculations, and it is described that a continuous dialogue will be held between the project owner and project manager to observe project developments.

There were seven participants, not including the two authors, including actors from the PEAB offices in Solna, Gothenburg, Helsingborg, and Malmö. The first meeting was spent describing the project description, the reasoning and motivations for wanting to include LCA in sustainability reporting, and what perceived benefits it might provide.

Transcriptions or recordings of the project group meetings could not be shared by the authors due to the sensitive nature of the information discussed.

The authors additionally attended an industry seminar about circular construction hosted by Ramboll Buildings, where they observed the participation of various actors from the construction industry. This seminar provides a better understanding of how the construction sector itself pushes for CE and provides an understanding of how different actors within the construction work together for the purpose of circular construction.

3.3 Data analysis

The purpose of the thesis is to investigate the barriers for industrial transition to CE within the construction industry. Therefore a figure was created that describes the barriers of CE in the construction industry according to the most prominent, relevant and cited construction sector CE literature featured in ABS-chartered journals (Figure 3). The barriers presented in the figure will then be cross examined with the identified barriers presented by the respondents in the interview study to confirm if the barriers in literature are in agreement with the practitioners of CE in the

construction sector, which will serve as the analysis via the part of the coding process.

Thus, the barriers gathered from interviews with employees at PEAB working with circular construction must be classified according to the aggregated barriers in order to facilitate the analysis of data and provide validity and replicability for the data analysis process. One common way of achieving this in qualitative case studies is via a coding process, which has been adapted in this study (Auerbach & Silverstein, 2003).

3.3.1 Coding

Coding is a common method in qualitative research and assists in conducting qualitative case studies, thus the authors found it appropriate to adapt that method for the data analysis (Auerbach & Silverstein, 2003).

To classify and code information presented in the interviews a data structure is created (Table 17:). The barriers presented within the literature are categorized in accordance with the regime actors affecting industrial transition according to the multi-level perspective on transition framework by Geels & Schot (2007). Barriers are then further aggregated and subcategorized based on similarities in literature (Figure 3). The reasoning being that transition from a linear economy to a circular one, is a form of industrial transition, which is also true of the push for CE transition within the construction sector (Chizaryfard, 2023).

The regime actors introduced by Geels & Schot, 2007, which need to be in agreement for industrial transition are: markets, industry, policy, science, technology, and culture. These regime actors were used as barrier categories to categorize and code the primary data of interview results.

Within the data structure, barriers within the six main barrier categories are then further categorized into subcategories depending on their similarities. This resulted in the subcategories of materials, tools and processes and

complexity within the technology category. It resulted in uncertainty and financial subcategories within the markets category. The culture category contained the interest and attitude subcategories. The subcategories: lack of information and information diffusion was found within the science category. The subcategories: incentives, integration and risks and regulations were found within the industry barriers. Finally, within the policy category, the subcategories of Regulations and Ownership were identified.

The data structure was used to code barriers presented from the interviews in an excel file (Table 17: Data structure). The excel file was divided into six columns: Barrier category and subcategory, Barrier, Quote, Data-source(s), Secondary data and literature view, and Analysis.

The coding process of the data analysis Table went as follows:
First, an interview was conducted in accordance with the steps outlined in the interview guide. Secondly the authors repeatedly rewatched the recordings and examined transcripts produced from the interviews, highlighting keywords and phrases which could be interpreted as barriers, which became the codes used in the study. This leads to rounds of discussion among the authors about which barriers are equivalent or comparable to the highlighted keyword and phrase. After author agreement, the barrier is placed in the correct barrier dimension alongside the phrase or keyword. If the barrier has already been identified before from another data source, the later interview is placed directly underneath the previous one.

After the quote has been attributed a quote and an author describing that quote, secondary data is presented in the fifth column from the literature which first described the barrier aspects. The purpose being to serve as a frame of comparison between the practitioner's viewpoint of the barrier compared to the theorists, which can allow the authors to analyze contradictions and agreements between practitioners and theorists. Another goal of the analysis is to find the most common themes and barriers as mentioned by the data sources, which can then be used to explore the

connectedness and relations of the barriers identified in the study and thus present which barriers are in priority to be overcome.

3.4 Research ethics

To protect the identities of the participants within the study, the participants of the interviews and participants of the observations were anonymized. This allowed the respondents to freely express opinions free of any potential consequences.

At the start of each individual interview the respondents were given the information that the interviews were anonymous and that their identities would be protected within the study. Respondents were notified that they were being recorded and that the interviews were being transcribed. At the start of every interview all respondents were notified that they had the option to opt out of the recording if they wished. The respondents were additionally notified that they had the freedom to strike any statements from the records and that they had the opportunity to change statements retroactively if they wished.

Considering the thesis was conducted in cooperation with PEAB, there was a risk that the study could be affected by conflicts of interest. However, the authors have never received any incentives from the firm, monetary or otherwise. The authors were solely interested in the empirical data the firm could provide and the firm had no influence over the thesis contents.

To avoid interpretive differences, the authors went through the transcriptions and interview recordings both individually and then collectively to confirm that the authors had the same interpretation of respondent statements. This was conducted to ensure that respondents' statements were presented and understood as accurately as possible.

4. Findings

The content in this section presents the study's findings and primary empirical data. First, the results of observing an LCA implementation project group and a construction industry seminar about CE are presented. Secondly, the primary form of empirical data collection: semi-structured interviews with construction sector professionals regarding the barriers of CE are presented according to the data structure (Table 17).

4.1 Observation results

4.1.1 LCA project group observation

The project group for LCA implementation in sustainability reporting was held in one-hour-long sessions once per month. The meetings included actors across several regions, as the project's end goal was the widespread implementation of LCA calculations across the firm.

Background information about the specifics of what LCA calculations are presented during the introduction of the project. It was additionally presented how PEAB aims to delimit its LCA calculations. In this case, the calculations are delimited to exclude calculations on direct emissions in, waste management, final material handling, and effects outside the life cycle.

The primary motivations for implementing LCA calculations are described as providing strategic options for decreasing CO2 emissions throughout the entire lifecycle of a building, something PEAB has focused much on in recent years (*PEAB Annual Report*, 2022). The project is additionally described as contributing to internal knowledge and competence in sustainability reporting, providing PEAB with a competitive advantage.

Toward the end of the session, the potential future integration of LCA calculations with future iterations of their Building Information Management (BIM) software is discussed and described as a possible future project. This is an example of what Pomponi & Moncaster (2017) suggests, that LCA calculations with supplementary support from design tools such as Building information management (BIM) can be integrated to enable the effective implementation of CE activities.

However, potential CE economy implications are not discussed or mentioned at any time during the sessions, meaning that they are working with methods that could lead to circularity, such as LCA and BIM implementation but were not explicitly aiming for circularity. However, during the interviews, it was found that one of the motivations of the project owner behind the project was to build competence regarding circularity within the firm. This alludes to the conservativeness of the construction industry barrier due to the project owner feeling that they had to sneak in the concept for it to be accepted within the project group and among their peers and to avoid pushback.

4.2.2 Circular economy seminar observation

Ramboll organized a seminar on circular construction, attracting participants from various roles within the construction industry, including municipalities, contractors, consultants, and property owners. The diverse representation highlighted the broad interest in circular initiatives. The seminar focused on exploring ways to establish circular construction as the standard practice. During the discussions, several ideas emerged on how to achieve this goal, including the implementation of laws and regulations such as VAT tax incentives, incorporating preservation and reuse into standard procedures, encouraging client demand for recycled materials, offering incentives like tax reductions, and requiring projects to justify their inability to use recycled materials.

The seminar presented six reasons why to adopt circular construction. First, it was highlighted that the entire real estate industry in Sweden contributes up to 40% of CO2 emissions, signaling a significant opportunity for emission reduction. Second, Sweden's resource utilization is currently only 3.4% circular, which is below the global average (Jensen & Stigson, 2022). This indicates ample room for improvement and increased circularity. Thirdly, circularity is crucial for achieving global sustainability goals, particularly in the context of promoting the 12th goal: sustainable production and consumption. Fourthly, the EU taxonomy emphasizes the importance of circularity, introducing demands and criteria in this regard. Fifthly, Boverket (Swedish National Board of Housing, Building, and Planning) is in the process of developing a climate declaration for construction projects. Finally, recycled construction materials are considered to have zero CO2 emissions, further emphasizing their environmental benefits in achieving circularity.

During the seminar, circular construction was discussed from phase-specific actions. Related to the project development perspective, there was much focus on retaining and reconditioning existing buildings. As well as the need to connect deconstruction with new construction if necessary. To do this, a project developer explained the need to design for circularity early. They suggest using construction techniques that allow for flexibility and deconstruction together with cooperation between all the actors in the early stages of construction projects.

Further, actions were presented related to different phase-specific challenges on how to facilitate a circular construction. Such as within the construction phase, there are challenges to optimize resource usage, how to minimize waste, energy, and usage of toxic substances. During building administration, there's a need to overcome challenges regarding how to save information regarding the building and continuously update it, as well as how to extend the lifespan of the current building and its components. Finally, it is essential to take action to address the challenges associated

with the deconstruction phase, including determining what can be realistically dismantled, identifying areas with the highest waste generation, and devising strategies to minimize waste during the process.

A specific barrier presented during the seminar was that using recycled material made obtaining environmental and insurance certifications on reused material impossible. Presenting a discussion on the need to adopt a new certification for CE material to overcome the barrier. Another barrier was that there was a need for a marketplace for reused material that all the actors in the industry could use. Finally, barriers were presented related to proper documentation of what exists in a building were identified in order to enable deconstruction.

4.2 Interview results

This section presents the findings of the interviews. The barriers found in the interviews are then aggregated and categorized by; technology, science, markets, policy, industry, and culture. All of these were adapted from the regime actors in Geels & Schot's (2007)s. Multi-level perspective (MLP) framework on transitions. The respondents' statements are then presented, synthesized, and analyzed within these categories and their subcategories based on the aggregation of literature barriers (Figure 3) and the data structure sheet (Table 17: Data structure).
The sub-categorization was made to suit better a synthetization of influencing factors related to industrial transition and barriers to CE in the construction industry.

4.2.1 Culture

Within the culture barrier category, the barriers of ‘’The conservativeness of the building industry’’, ‘’Scarce interest and demand from clients’’ and ‘’The social dimension of construction’’ were represented in the interviews (Andersson & Buser, 2022; Çimen, 2021; Giorgi et al., 2022). The conservativeness of the building industry barrier is represented in the ‘’Attitude’’ subcategory while the scarce interest and demand from clients is

represented in the ‘’Interest’’ subcategory, meaning that all subcategories were represented in the interviews. However, cultural factors are the least represented of the barrier categories in the empirical data, only presenting 3 barriers.

Culture: Interest

Cultural beliefs and values, together with practices and norms, were identified during the interviews. Where respondents expressed challenges related to their interest in adding more circular or sustainable practices. Creating a subcategorization focused on cultural interest. Barriers found were:

Barrier	Quote	Data source(s)
Scarce interest and demand from clients	"As a client you want to add as few requirements as possible on contracts to keep the price as low as possible"	Interview #2: Project manager
	"Reducing CO2 emissions are difficult to motivate clients to invest in, as they don't have pay more if they create more emissions"	Interview #6 Technical energy specialist

Table 4:Culture: Interest barriers

Scarce interest and demand from clients

- Clients do not value sustainability and circularity enough due to the perceived increased cost.
- Clients avoid adding new requirements related to circular principles before seeing profitability and demand for it.

Culture: Attitude

Cultural symbols and meanings, cultural practices and norms, and cultural resilience was identified during the interviews. Where respondents expressed challenges related to the attitude to change in the construction industry. Creating a subcategorization focused on cultural attitudes. Barriers found were:

Barrier	Quote	Data source(s)

The conservativeness of the building industry	"Everything which is new is difficult and experienced as expensive in the construction industry"	Interview #2: Project manager
	'I am curious about the circular economy concept. However, the industry is very conservative and therefore things are the same as they usually are''	Interview #3: Site manager
	"Compared to other industries, i think the construction industry is a little conservative, but there is happening stuff"	Interview #6 Technical energy specialist
The social dimension of construction	"There's a need to create building in a timeless architecture, currently we tear down buildings after thirty years"	Interview #8, Construction manager

Table 4: Culture: Attitude barriers

The conservativeness of the building industry

- There's a resilience to change, as it is experienced as difficult and expensive.
- Practices are deep-rooted, where the industry prefers current practices.

The social dimension of construction

- Over time, the social aspect of architecture evolves, often resulting in a decrease in sustainability due to premature demolition before reaching the end-of-life stage.

4.2.2 Technology barriers

Technology can act as a barrier on multiple levels, causing challenges related to material, tools and processes, and complexity. This was apparent with the interview results containing nine different barriers, the most out of any category, while also having all of the subcategories being represented. The most prominent ones being ‘’The existing building stock, which has not been designed for circularity’’ being represented in more than half of

interviews, and ‘’Lack of tools and guidelines for the design of circular products and buildings’’ which appeared in three out of eight (Adams et al., 2017; Hossain et al., 2020).

Technical: Material

Technical innovations, infrastructural requirements, technological lock-in, knowledge, and standards and regulations were identified during the interviews. Where respondents expressed challenges related to the material and current building stock. Creating a subcategorization focused on technical material. Barriers found were:

Barrier	Quote	Data source(s)
The existing building stock, which has not been designed for circularity	'Materials used 15 years ago might not be able to be used today due to changing material demands and standards"	Interview #3: Site manager
	'To reuse a working 50-year-old door; you need to take functionalities such as fire- and sound resistance or a specific size for wheelchairs to pass. Technically the door works, but due to a change in standards, the door cannot be used today."	Interview #4: project manager infrastructure
	'Deconstruction is currently not considered in construction sites, Sweden uses a lot of soldering and welding on steel beams for example, which compared to the UK which uses a lot of screws instead, makes it more difficult to reuse"	Interview #5: group manager energy and climate
	I have previously only focused on the operational phase, reducing energy use, but now we have come so far down that the question is, should we really have such thick walls or not? When you haven't looked at energy consumption and such to build the house, maybe you shouldn't have so much insulation. Insulation may have a worse climate impact than what you save.	Interview #6 Technical energy specialist
	"Currently, the construction of buildings is done with welding or concrete with reinforced stubs, making it difficult to deconstruct due to most of the material or building elements breaking. There's a need to construction building using deconstructable methods, using bolts"	Interview #8, Construction manager
	"The problem is from extra demands from customers or architects that make construction use those	Interview #8, Construction

	methods,	manager
Other design challenges include the durability of recycled materials	"There's a need to know what type of material you have if the material has been exposed to fatigue loads because you can't use it if it has.	Interview #8, Construction manager

Table 5:Technology: Material barriers

The existing building stock, which has not been designed for circularity

- Practitioners cannot reuse material due to changes in standards and regulations.
- Current construction methods are not great for purposeful deconstruction to salvage construction materials. Specifically the use of a lot of soldering and welding on steel beams, which is more difficult to deconstruct than ones that are screwed together.

Other design challenges include the durability of recycled materials

- There's a lack of standards to gain information related to the durability of the material at the end-of-life of a building.
- Material and products need to meet certain durability requirements, which is difficult to prove with reusable or upcycled materials.

Technical: Tools and processes

Technical innovations, infrastructural requirements, technological lock-in, knowledge, and standards and regulations were identified during the interviews. Where respondents expressed challenges related to the lack of standards and tools to support circular construction. Creating a subcategorization focused on technical tools and processes. Barriers found were:

Barrier	Quote	Data source(s)
Lack of tools and guidelines for the design of circular products and	"There need to be directives to study in detail on how to prepare building for circularity, with standardized guidelines could have helped"	Interview #2: Project manager

buildings		
	'Current calculations does not consider the specifics of the product, only the cost, so when calculating the cost of a roof for example it is impossible for us to tell the specifics of the products." "this causes information management issues, between parties, is easily solvable but creates additional work"	Interview #5: group manager energy and climate
	'We need to find applicable tools that enable us to work more with circularity"	Interview #7: Head of sustainability
	"There are demands to be met when working with warranties, you do what you have to meet those requirements, nothing more, when asked why we don't do more, for example why don't we add solar panels to the roofs was due to were already reaching the goals and there's no need"	Interview #6 Technical energy specialist
The lack of market mechanisms to promote materials recovery and an ineffective process chain for recovering	'We would like support in picking up and procuring remaining material from building sites, it is way easier and cheaper to get rid of material by throwing away than any other way, and a material recovery vehicle could solve that issue"	Interview #3: Site manager
Lack of a standardized information system about an international resource bank	"There is value in working with recycling within an organization. However, there are uncertainties working between companies, as its costly to keep and store recycled material that someone might need in the future"	Interview #2: Project manager

Table 6: Technology: Tools and Processes barriers

Lack of tools and guidelines for the design of circular products and buildings

- There's a lack of tools to promote circularity.
- Standards and guidelines could support working with circularity when there's a lack of knowledge.
- Current tools do not consider product specifics.

The lack of market mechanisms to promote materials recovery and an ineffective process chain for recovering

- Currently, there is a lack of infrastructure to support the recovery of material.

Lack of a standardized information system about an international resource bank

- There are many difficulties in creating an international resource bank

Technical: Complexity

Technical innovations, infrastructural requirements, the interaction between technologies, technological lock-in, knowledge, and standards and regulations were identified during the interviews. Where respondents expressed challenges related to the complexity of the industry and projects. Creating a subcategorization focused on complexity. Barriers found was:

Barrier	Quote	Data source(s)
Challenges such as tracking material stock and flow.	'I would like to see some kind of database of available reusable material, we don't know what kind of material we currently have and where"	Interview #3: Site manager
Complexity of the supply chain	"Each step in the supply chain can act as a barrier for circular construction"	Interview #4: project manager infrastructure
geographical differences	"When wanting to work with recycled material, there's a complexity in obtaining material, where to find it, then there will be a need to research and evaluate the material, then transporting it"	Interview #4: project manager infrastructure
	One of the barriers to reuse of construction materials is that if it is justifiable in environmental impacts. If a material has to be transported from Malmö to Norrland for construction, it can be difficult to justify that.	Interview #7: Head of sustainability

Challenges such as tracking material stock and flow.	Project Development and design need to be done in early stages, with up to 2 years before construction, where you need to decide on material early, and with reused material there is a difficulty related to obtaining correct material at the right time, if you don't want to house the material up to 2 years"	Interview #4: project manager infrastructure

Table 7:Technology: Complexity barriers

Challenges such as tracking material stock and flow.

- There are wishes to simplify tracking material stock and flow via material databases to enable reuse of building material.

The complexity of the supply chain

- Each construction project has multiple stages and actors, making it difficult to synergize and implement a circular construction across the value chain.

Geographical differences

- Transportation is a difficulty, as there are time, economy, and sustainability constraints when working with recycled material due to limited supply.

Challenges such as tracking material stock and flow.

- There is a lack of infrastructure to successfully design with recycled material due to limited supply.

4.2.3 Market barriers

Market barriers were prominently featured within the interviews, showcasing challenges in all the facets and levels of the firm which might impede the adoption of CE and CE activities. The respondents presented seven barriers, with ‘’Uncertainty about the return on investments’’ being

the most represented barrier across all of the interviews, being represented within six out of eight interviews (Shooshtarian et al., 2022). Both the subcategories of ‘’Uncertainty’’ and ‘’Financial’’ were represented in the interviews; however, the uncertainty category was far more represented, outnumbering the barriers five to two.

Market: Uncertainty

Market demand and customer preferences, market competition, price signals, and economic incentives, market infrastructure and support systems, and market network and interactions were identified during the interviews. Where respondents expressed the uncertainty about the economic benefit related to adopting CE in the construction industry. Creating a subcategorization focused on market uncertainty. Barriers found were:

Barrier	Quote	Data source(s)
Unclear financial case	'Currently it is difficult to see circularity and re-use of materials as profitable''	Interview #1: Sustainability manager project development
	'There is more new construction than demolition, and according to economics low supply can lead to higher cost. That in addition to the need for warehousing the materials, which might need the creation of a new firm within PEAB to do, meaning further higher costs which will make it difficult to make reuse of materials profitable."	Interview #5: group manager energy and climate
Uncertainty about the return on investments	'I don't think potential reuse would result in saving money, i think the environmental aspect is the big benefit."	Interview #3: Site manager
	Currently it is difficult to see circularity and re-use of materials as profitable''	Interview #1: Sustainability manager project development
	"There is value in working with reuse within an organization. However, there are uncertainties working between companies, as its costly to keep and store recycled material that someone might need in the future"	Interview #2: Project manager
	People think reused material is free. However, in practice it costs more than virgin material. This is especially true if the material must be upcycled or additional work in order to be fit for construction	Interview #4: project manager infrastructure

	purposes. However, we can see that reusable bricks can become profitable, as it is easy to deconstruct and test material quality.	
	'There is more new construction than demolition, and according to economics low supply can lead to higher cost. That in addition to the need for warehousing the materials, meaning that the higher costs will make it difficult to make reuse of materials profitable."	Interview #5: group manager energy and climate
	"it's more expensive to work with reused or sustainably"	Interview #6 Technical energy specialist
High uncertainties and risks of consistent supply of recycled material	'There might be a supply and demand issue, where would potentially have too much of certain reused materials and too little of others''	Interview #1: Sustainability manager project development
	'There is more new construction than demolition, and according to economics low supply can lead to higher cost. That in addition to the need for warehousing the materials, which might need the creation of a new firm within PEAB to do, meaning further higher costs which will make it difficult to make reuse of materials profitable."	Interview #5: group manager energy and climate
Economic uncertainty	'Due to current world events money is tighter than normal which might affect firms' ability to experiment and innovate''	Interview #1: Sustainability manager project development
	The current recession might possibly be a barrier that slows CE adoption, it will be interesting to see the effects in the long run	Interview #7: Head of sustainability
Lack of unproven business cases underpinned by viable business models	'It is hard to find circular business models that are scalable to a whole enterprise. We have seen smaller projects that have worked well like Varvstaden.	Interview #7: Head of sustainability

Table 8:Market: Uncertainty barriers

Unclear financial case

- It is seen as not profitable to use recycled material and circular principles due to multiple barriers.

- Supply and demand issues exist, creating uncertainty and unclear financial cases.
- Lack of market infrastructure to make a financial case.

Uncertainty about the return on investments

- There's a risk of using recycled material; money made by recycling can be lost due to additional costs in transportation, upcycling, and storage of the material.
- Different perspectives related to the uncertainty of return of investment: Costly, larger focus on sustainability rather than profitability and requires high investments to operationalize.

High uncertainties and risks of consistent supply of recycled material

- There's a lack of market network and interaction between actors to support the use of recycled material.
- There is more construction than deconstruction, which places a hard limit on the potential supply of reusable materials.

Economic uncertainty

- Additional pressure from the socio-technical landscape reduces organizations' ability to experiment and develop circularity.

Lack of unproven business cases underpinned by viable business models

- There are not enough support systems to scale up current business cases.
- Circular construction projects have scalability issues due to needing several unique conditions to be met, such as in the case of Varvsataden, which makes it impossible to scale up to an entire business.

Market: Financial

Market demand and customer preferences, market competition, Market Regulations and Policies, and economic incentives were identified during the interviews. Where respondents expressed the lack of financial and economic incentives related to adopting CE in the construction industry. Creating a subcategorization focused on financial aspects. Barriers found was:

Barrier	Quote	Data source(s)
Lack of financial incentives	While counties and municipalities push for circularity, they tend to prioritize price over sustainability, i would like to see more incentives on sustainability or circularity efforts'	Interview #1: Sustainability manager project development
Today, prices are low, making it uneconomical to reuse	"40 years ago we did reuse all the nails and material from the buildings, today however, we just throw and burn it. This is due to the high salaries, it's not worth it"	Interview #8, Construction manager

Table 9:Market: Financial barriers

Lack of financial incentives

- There is a lack of financial incentives for companies to adopt more sustainable methods as it is weighed less than economic ones in public procurement.
- General push of circularity coming from municipalities and counties, however, this push is not financially incentivized as they tend to prioritize price over sustainability.

Today, prices are low, making it uneconomical to reuse

- The market competition from virgin material is so high that recycled material can't compete.

4.2.4 Science barriers

Within the interviews, science barriers were mainly tied to the knowledge dimension rather than the scientific contents of the CE concept. This was represented by the ‘’Lack of knowledge’’ barrier being presented in five out of eight interviews, and thus being one of the most presented barriers in the interviews.

Science: lack of information

Technological knowledge generation, technological paradigm shifts, technological development, and diffusion were identified during the interviews. Where respondents expressed challenges related to the knowledge related to adopting CE in the construction industry. Creating a subcategorization focused on knowledge aspects. Barriers found were:

Barrier	Quote	Data source(s)
Lack of knowledge	'While i see circularity as a necessity, we are all newcomers to it, it is a bit of unexplored ground for us	Interview #1: Sustainability manager project development
	'As far as i am aware, PEAB is working with circularity a lot, however it comes in waves, i do not have much personal experience however.''	Interview #3 Site manager
	'Circular economy is a new concept for the industry, there is some slight pushback., but less than i expected''	Interview #7: Head of sustainability
	''There are a lot of difficulties working with buildings if you're aiming to deconstruct it. For example you could theoretically skip joint casting, to enable deconstruction. But then there will be noise problems, where you need to add steel welding to combat that problem, so many solutions add different problems. Making it more difficult than you think.''	Interview #8, Construction manager
	There can be a lack of experience when working with sustainability and circularity	Interview #6 Technical energy specialist

Table 10:Science: Lack of information barriers

Lack of knowledge

- The generation of knowledge is slow related to CE.

- The diffusion of knowledge is slow, related to CE.
- There are technical difficulties related to a paradigm shift to support a circular construction.

Science: Information diffusion

Technological diffusion was identified during the interviews. Where respondents expressed challenges related to the development and diffusion of information related to CE transition in the construction industry. Creating a subcategorization focused on information diffusion. Barriers found was:

Barrier	Quote	Data source(s)
N/A	'Currently, the construction sector only considers circularity as a method for sustainability, rather than the wider perspective of circular economy. There is a journey the construction sector must do there". "There is a difference of understanding and focus on different things in discussions regarding CE currently, such as Circular flows VS carbon emissions." "One of the challenges for circularity in a project development role is that it is heavily tied to sustainability questions, however, you can still be climate neutral but still be bad for the planet due to the amount of resource usage"	Interview #7: Head of sustainability
	‘'I have previously only focused on the operational phase, reducing energy use, but now we have come so far down that the question is, should we really have such thick walls or not? When you haven't looked at energy consumption and such to build the house, maybe you shouldn't have so much insulation. Insulation may have a worse climate impact than what you save.’’ "We are currently only focusing on the parameter climate, maybe we should look into other as well"	Interview #6 Technical energy specialist

Table 11:Science: Information diffusion barriers

Unidentified barriers:

- CE is only seen as a sustainability method of reducing CO2 emissions while not considering the other concepts, such as new value propositions and waste management.

4.2.5 Policy barriers

Law and regulatory issues, specifically related to ownership, were frequently presented in the interviews. All subcategories were described at some point during the interviews; however, within the regulations subcategory, there were more barriers that had no suitable parallels in the views of theorists than ones that did. On the other hand, ownership issues and challenges related to reusable material were commonly presented in the interviews and had suitable parallels with theorists.

Policy: Regulations

Regulatory frameworks, supportive policy instruments, standards and certification, sector-specific policies, and public procurements were identified during the interviews. Where respondents expressed challenges working with circularity due to existing laws and regulations. Creating a subcategorization focused on regulations. Barriers found were:

Barrier	Quote	Data source(s)
Lack of environmental regulations and laws which is driving the rest of the barriers to the circular economy	"Some regions in Sweden has different requirements, some need to work with eco-concrete or recycled material, however it's not applied everywhere"	Interview #2: Project manager
N/A	'Currently there are too many upcoming environmental regulations which causes too many quick and inefficient changes which create more practical challenges which simply prevent us from using leftover materials from a next-door building project"	Interview #3 Site manager
	"There are many laws and regulations related to construction, there are demands on stairs, doors, and so on which need to be fulfilled, which hinders the reuse of material as they don't fulfill today's standards. Making it impossible to reuse.	Interview #4: project manager infrastructure

Table 12:Policy: Regulations barriers

Lack of environmental regulations and laws which is driving the rest of the barriers to the circular economy

- Public procurement is valued differently depending on the region.

Unidentified barriers:

- Laws and certifications hinder the reuse of material on site.
- Standards and certifications make reuse difficult, making material and products lose value.

Policy: Ownership

Regulatory frameworks, supportive policy instruments, standards, and certification were identified during the interviews. Where respondents expressed challenges working with circularity due to a lack of warranties and the risk of ownership of recycled material. Creating a subcategorization focused on ownership. Barriers found were:

Barrier	Quote	Data source(s)
Lack of legal warranties on recycled or reused materials	'Guarantees might be a concern the entire industry might need to solve when working with reuse''	Interview #1: Sustainability manager project development
	"No one want to work with recycled material due to there are no warranties, due to the lack of information/papers on the material, leaving actors unable to give warranties to the customer"	Interview #4: project manager infrastructure
	'Large construction enterprises are hesitant with working with reusable materials due to lack of documentation, if something fails, who carries responsibilities?''	Interview #5: group manager energy and climate

Table 13: Policy: Ownership barriers

Lack of legal warranties on recycled or reused materials

- Companies are not willing to take the risk of not having documented warranties on the material.

4.2.6 Industry barriers

All industry barrier subcategories were presented within the interviews, however, all respondents perceived different barriers depending on their perspectives. This led to four different barriers being perceived across four different interviews.

Industry: Integration

Market Dynamics, Industry Networks and Clusters, and Value Chains were identified during the interviews. Where respondents expressed challenges working with circularity due to a lack of network and value chains to support a circular construction. Creating a subcategorization focused on Integration. Barriers found were:

Barrier	Quote	Data source(s)
lack of integration of sustainable waste management and potential reuse	"There is a place where we store material storage of disassembled materials. However, there's a lack of knowledge how to access it"	Interview #2: Project manager
Inadequate communication with clients, designers, and subcontractors	"It can be difficult to get informations related to the material in itself, when wanting to do LCA calculations"	Interview #6 Technical energy specialist

Table 14: Industry: Integration barriers

lack of integration of sustainable waste management and potential reuse

- PEAB currently has a place where they store disassembled materials. However, there is a general lack of knowledge on how to access the materials therein.

Inadequate communication with clients, designers, and subcontractors

- There are difficulties wanting to get information related to specific material from subcontractors.
- There's a need to have a conversation on the viability of using recycled material in the early stages in order to successfully implement CE in a project rather than having clients make unreasonable demands.

Industry: Incentives

Market Dynamics, Industry Networks and Clusters, Business Models, and Value Chains, and Investments were identified during the interviews. Where respondents expressed challenges working with circularity due to a lack of network actors and incentives for actors to work with a circular construction. Creating a subcategorization focused on Incentives. Barriers found were:

Barrier	Quote	Data source(s)
Lack of incentives for actors in a supply chain to adopt CE	"Currently there's a lack of actors working with CE"	Interview #4: project manager infrastructure

Table 15: Industry: Incentives barriers

Lack of incentives for actors in a supply chain to adopt CE

- There are not enough incentives for actors to transition to CE.

Industry: Risk & Uncertainty

Market Dynamics, Industry Networks and Clusters, and Value Chains, and Investments were identified during the interviews. Where respondents expressed challenges working with circularity due to supply risk and decisions that need to be made to support a circular construction. Creating a subcategorization focused on Risk & Uncertainty. Barriers found were:

Barrier	Quote	Data source(s)

Supply and business risk	Project Development and design need to be done in early stages, with up to 2 years before construction, where you need to decide on material early, and with reused material there is a difficulty related to obtaining correct material at the right time, if you don't want to house the material up to 2 years"	Interview #4: project manager infrastructure
	"To work with circularity there's a need for someone to stock up on material and a market to sell the material to. Currently this does not exist, making it difficult to work with reused material"	Interview #8, Construction manager

Table 16: Industry: Risk and uncertainty barriers

Supply and business risk

- The lack of actors can cause a supply and business risk for construction companies.

4.3 General interview results

As the interviews were conducted in a semi-structured interview format, the respondents were able to provide information not explicitly related to barriers of CE transition. Still, they might be applicable to CE transition in other forms.

A common sentiment presented in the interviews was the wish for better infrastructure regarding procurement and waste management. In Interviews #2 and #4, the prospect of having a public online marketplace for unused and reusable materials is something they would like to see in the industry. This would enable more reuse within the construction sector. However, PEAB already has this internally via Varvsstaden. Varvsstaden has a material bank of available construction materials for upcycling, recycling, and reuse, all of which are available publicly via their homepage (Tornkvist, 2015).

When respondent #4, the project manager of infrastructure at Varvsstaden, described this material bank, they described it as being created for the express purpose of keeping track of which materials were available for reuse. However, in practice, the material bank was less useful for the facilitation of materials and more so as a showroom and museum in which

Varvsstaden could illustrate their work on material reuse for both the public and shareholders. The respondent further clarifies that the material bank was not very useful for its original purposes but has been useful for educational purposes, showcasing the positive effects of material reuse and might inspire future projects.

Respondent #4 elaborates that for the material bank to be useful for its original purposes, there would need to be a much larger supply of materials with all the necessary documentation, certifications, guarantees and etcetera. They additionally describe that for this to work, a common resource bank must be created that includes most large industry actors to pool together their resources which otherwise would have gone to landfills. The respondent likens this to the Swedish Ebay alternative ‘’Blocket’’, stating that you need a wide variety of buyers and sellers in one place; no one would use it if there were only one individual on there. The respondent additionally describes CCbuilds material bank as a good start for having an industry-wide material bank for reusable material.

The head of sustainability, respondent #7 explained that there are different pilot projects happening in the industry where innovative and sustainable methods are being tested. However, they found it very difficult to scale circular business models to fit the whole organization. The material bank at Varvsstaden is an example of this; as respondent #4 explained, the material bank at Varvsstaden ended up more as an educational purpose than practical in his work, showcasing the difficulty of scaling up circular business models.

Respondent #7 also describe that one of the primary motivations behind the LCA project is to incorporate more circularity and build more knowledge of circularity within the firm, in addition to the prospect of integrating it with BIM methods in the future. This way of enabling circularity is supported by the literature with Pomponi & Moncaster, (2017) stating that LCA calculations with supplementary support from design tools such as Building information management (BIM) can be integrated to enable effective

implementation of CE activities. One of respondent #7´s main goals for the project was to consider the entire life cycle and achieve closed-loop systems, with a primary focus on reducing CO2 emissions, while also expressing that climate is crucial; it is not the only factor in the end result. Via the LCA project, respondent #7 aims to introduce and promote circular thinking throughout her organization and to quantify circular benefits with calculations rather than abstract concepts.

For additional practices which could enable circularity, respondent #3 described that they would like to see a truck that could periodically arrive at the construction sites to pick up leftover and unused material that would otherwise go to landfills for convenience and space reasons. These trucks could additionally be used to deliver those construction materials to other construction sites that need them. Respondent #3 added that the available space for materials is always an issue and described that such a system would alleviate the issue of construction sites discarding materials to save on the construction site. The respondent additionally hypothesized that for such a system, they would most likely be more of a material donator than a material purchaser due to certain environmental certification demands on material which are a requirement on many of his construction sites.

From interview #1 and interview #3, PEAB was described to be a firm with a high sustainability profile and motivated to achieve the sustainability goal of being climate neutral by 2045. However, Interview #2 highlighted that PEAB is one of the major actors in the Scandinavian market and, due to its size, is rarely the first to act and experiment with new and unproven business activities, especially with sustainability activities, despite PEABs sustainability profile.

Respondent #4, the project manager at Varvsstaden described positive experiences working with CE principles, they specifically described that in addition to all the sustainability benefits such as CO2 and waste reduction, working with reusable materials has aesthetic benefits which creates a

timeless look. Within PEAB, the Varvsstaden project was seen in a positive light, being brought up as a positive example of a Circularity project by multiple respondents, such as respondent #1, #2, #5. and #7.

The push for CE within the construction sector seems to be perceived differently between respondents. When comparing interview #1 and interview #2, one can see large perspective differences between practitioners. Respondent #1 is working with design and described the push for CE as very noticeable and circularity being a necessity for the future. When contrasted with respondent #2's client side perspective however, the push for CE was not very noticeable and not a goal when placing construction demands. Respondent #4, the project manager for Varvsstaden additionally describes that there needs to be a larger push for circularity, specifically a push for more deconstruction and reuse of construction materials from both municipalities and the industry to enable more circularity projects.

5. Analysis

This section analyzes the findings of the interviews. The respondents' statements and perspectives on the barriers to CE transition are compared with the literature views on the same barriers.

5.1 Culture barriers

Interest

Scarce interest and demand from clients

Andersson & Buser (2022) describes that the scarce interest and demand from clients was one of the main reasons why the construction sector has yet to reach the expected reuse and recycling levels. According to respondent #6, it is challenging to encourage clients to invest in sustainable options because they are not incentivized to pay extra for such choices. This means that the literature description of the barriers clearly agrees with the

perspective of the project management practitioners (Andersson & Buser, 2022).

Key takeaways from the interview with respondent #2 and #6 is that there is a scarce interest and demand from clients due to a lack of pricing and cost incentives. The lack of financial incentives is a barrier described in the literature, suggesting that the barriers might be linked (Chen et al., 2022; Shooshtarian et al., 2022). As described by the respondent, the uncertainty regarding the potential profitability of reusing construction material might be tied to the unclear financial case barrier, creating a further connection between the scarce interest and demand from clients barrier and other barriers (Adams et al., 2017). Respondent #6 further highlighted this statement that clients are more interested in reducing their own costs and would instead invest in options that benefit them than the environment. For this to change, there might have to be pressure from other sources, such as financial incentives, law regulations, or market demands.

Attitude

The conservativeness of the construction industry

When comparing these views with the literature view of the barrier: the resistance to the industry's transition to circularity is due to operators favoring traditional methods and practices with lower technological content, meaning there is a clear agreement between practitioners and theorists regarding the conservativeness of the industry barrier (Giorgi et al., 2022).

When further considering the statements of the respondents, it becomes clear that the construction sector tends to stick to what they know is working, which is creating further resistance to CE transition. Because when the industry is already resistant to change, it can become increasingly difficult to innovate, even when there are clear benefits and needs. There is also a risk that this barrier can embolden other barriers such as "short-term thinking", "scarce interest and demand from clients" and "low acceptance of ideas" (Adams et al., 2017; Andersson & Buser, 2022; Hossain et al., 2020)

5.2 Technology barriers

Material

The existing building stock, which has not been designed for circularity

To enable an increased circularity in the construction industry, there's a need to use materials at their highest possible value, with the principle issue that the current building stock has not been designed for circularity (Adams et al., 2017). The respondents present examples of this barrier, such as the 50-year-old door example that current construction methods are not great for purposeful deconstruction to salvage construction materials. Which causes issues related to the waste hierarchy, where products are not able to be reused directly, resulting in some type of upcycling, which increases the cost of reusing material.

Other design challenges include the durability of recycled materials.

The issue of material durability emerged as one of the key challenges identified by the interviewees. The uncertainty surrounding the current state of reused materials affects warranties due to their need to be following durability and frost regulations. It is essential for reused materials to meet these specific demands, but in the case of recycled materials, it becomes uncertain whether they can fulfill those requirements. This uncertainty creates an information barrier, as there is a need to test the material before it can be confidently reused. As well as to further compound the barriers related to the demand for recycled materials.

Tools and processes

Lack of tools and guidelines for the design of circular products and buildings

When asked what barriers exist when working with circularity, respondent #2 answered that “There need to be directives to study in detail on how to

prepare buildings for circularity, where standardized guidelines could've helped.". This is in line with Hossain et al. (2020) idea that to promote a CE in the construction industry; there must be guidelines for designing circular buildings and production in the conceptual stages, where respondent #2 works. Respondent #5 shares a similar view but from a different perspective, as they are active within the design phase of buildings when calculating costs. Respondent #5 states that current tools are not presenting material specifics within current economic calculations, which creates information management issues between parties, as only costs are known and there is less emphasis on the specifics of the construction material. Respondent #7 presents a more general perspective, stating that more tools must be found that can enable circularity.

Hossain et al. (2020) highlight that the lack of guidelines and standards in the construction industry can create challenges when trying to implement CE principles. Developers may not be encouraged to adopt innovative and sustainable construction practices, and instead, they may feel pressured to stick to traditional building methods to avoid additional demands. Respondent #6 presented similar views, that when reaching requirements there are no incentives to continue improving.

Lack of a standardized international resource bank

Respondent #3 presented the lack of a database where he can find available reusable material. Similarly Çimen (2021) suggests that the development of circularity and the need to reuse material comes with the challenge of tracking the material and for it to be easily available in a standardized recourse bank. The lack of a database was additionally seen as a significant barrier to the adoption of reusing material and achieving efficiency in material flow (Akinade & Oyedele, 2019).

The lack of market mechanisms to promote materials recovery and an ineffective process chain for recovering

Respondent #3 explained the lack of market mechanisms to promote materials recovery, where it is easier and cheaper to get rid of material by throwing it away than recovering it. This is a barrier that, according to Giorgi et al. (2022), is both a barrier and a driver in the management of construction and demolition waste. An ineffective process chain in material recovery can be a major barrier to circular construction (Giorgi et al., 2022).

Complexity

The complexity of the supply chain

Project complexity was highlighted multiple times by authors, with Chen et al. (2022) presenting that the whole life cycle of the building needs multiple different project participants, all from the beginning of the design phase to the End-of-life. Adding circular principles into projects involves the inclusion of demolition contractors and recycling plants, which introduces an additional layer of complexity to the supply chain network (Chen et al., 2022). Respondent #4 confirmed the notion that each step in the supply chain could act as a barrier to circular construction. The respondent further elaborated that for circular construction to be effectively implemented, it is crucial for all phases of the construction process to align and support circularity. They emphasized that each step in the supply chain can potentially act as a barrier to achieving circular construction practices. To succeed, there has to be a joint effort from all the participants in the network (Chen et al., 2022). Which, according to both respondents #2 and #4, happens rarely.

Challenges such as tracking material stock and flow

The long life span of buildings and the complexity of the supply chain cause challenges when tracking material stock and flow (Chen et al., 2022; Çimen, 2021). When asked, respondent #4 summarized it as project development and design needs to be decided in early stages, up to two years before construction. There's difficulty in reusing material as it's difficult to obtain

the correct material at the right time if you don't want to store the material yourself for up to two years. Chen et al. (2022) present this as a common issue where delay and unavailability of material can affect the demand for reused material.

Respondent #3 expressed further difficulties from their perspective when working with reused material, that they didn't know what kind of material was available and where. This is highlighted by Çimen (2021) that with the emerging understanding of CE, there's a need for tools to access the availability of reusable materials. This showcases similarities with the lack of tools and guidelines barrier, implying connectedness between these barriers.

Geographical differences

Further challenges when wanting to work with recycled material can be geographical differences. From respondent #4, there were complexities when wanting to source material, for example, where to find it, then to research and evaluate the material, then transport it. Hossain et al. (2020) specify that sustainable sourcing and supply chain of materials and products should be at the core as this may significantly influence the environmental impacts due to transport-related impacts. Respondent #7 presents a similar viewpoint; the potential reuse of materials must be justifiable from an environmental perspective; if materials must be transported halfway across the country for reuse, it can be hard to justify reuse from a Co2 emission perspective.

There is a difficulty in creating a framework for sustainability and circularity in the construction industry due to environmental and economic sustainability is very site-specific (Hossain et al., 2020). Since there's a need to consider what type of building, material, transport distances, and the political context (Hossain et al., 2020). By valorizing LCC or LCA in the design stage, methods suited for circularity and sustainability to the specific project can be achieved (Hossain et al., 2020).

5.3 Market barriers

Uncertainty:

Unclear financial case

Respondent #5 highlights the warehousing costs and the fact that there is much more construction than demolition going on. This puts a hard limit on the potential supply of reusable construction materials, which according to conventional economic wisdom, high demand and low supply entail high costs. It is stated by Adams et al. (2017) that there is a general belief within the industry that initial investors will not benefit from circularity and, therefore, will not seek out nor appreciate CE activities. A belief that the respondents of this study echoed.

Profits and costs are usually dominant factors in decision-making processes. Therefore if the profits are not seen for CE activities while costs are high, it might heavily affect the decision-making processes, which would enable the adoption of circular activities in construction projects (Adams et al., 2017). However, there is some divergence between the literature view and the view of respondents #1 and #5 regarding the barrier. Adams et al. (2017) describe the ‘’cost benefit for each party adopting the CE not being fully understood’’. However, the view of the respondent is that CE activities are a necessity for the future and therefore understand potential costs and benefits but are currently failing to see enough benefits.

Uncertainty about the return on investments

Uncertainty about the return on investments was a heavily featured barrier in the interviews, being present in the interviews of respondents #1, #2, #3, #4, #5, and #6, meaning that it was present within most interviews. This observation is consistent with Shooshtarian et al. (2022)s findings. In which they identified the Uncertainty about the return on the investment barrier, being one of the biggest barriers to CE transition.

High uncertainties and risks of a consistent supply of recycled material

Respondent #1 claims that there might be a supply and demand issue when working with the reuse of construction material, in which there could be too much of certain reused materials and too little of others. Respondent #5 further highlights the supply and demand issues, stating the fact that there is more construction than deconstruction which is placing a hard limit on potential supply.

While these claims certainly illustrate Hossain et al. (2020)'s barrier, specifically regarding the uncertainties of consistent supply, it does not explicitly describe the supply and demand uncertainties of working with circularity and reuse. In fact, none of the barriers within the current literature set of the study specifically highlight potential supply and demand challenges of circularity and reuse of construction material. This might imply a potential research gap and a barrier that researchers must further consider.

Economic uncertainty

According to the sustainability manager of project development in interview #1, money is tighter than normal due to current world events, which might affect firms' ability to experiment and innovate and thus affecting the push for circularity within the construction sector. According to Hossain et al. (2020), economic uncertainty is one of the largest barriers to CE transition within the construction sector. And while the economic state of socio-technical landscape due to current world events might certainly impact that, current barriers within the literature do not seem to spotlight the risks and uncertainties of current world events, which could possibly imply a literature gap. ''The supply and business risk'' barrier might also be close to the challenges respondent #1 and #5 is describing. However, the business risks are not increased by current world events. Rather, firms are less

willing to accept risks due to current world risks, something that is currently ignored within the current literature.

Lack of unproven business cases underpinned by viable business models

While requiring manufacturers to be responsible for the end-of-life phase of products is a challenge for unproven business cases underpinned by viable business models is considered a challenge in the literature, scalability issues, such as the ones presented in the findings are not (Adams et al., 2017). The scalability issues can explain why there is a lack of unproven circular business cases within the construction sector supported by viable business models. That there are few business cases and business models that are large enough to be applicable to the entire industry.

Financial:

Lack of financial incentives

Chen et al. (2022) describe that selective demolition is costly and is likely one of the main challenges hindering circular construction, which requires financial incentives in order to overcome it, and if the incentives are inefficient, it becomes a barrier. Shooshtarian et al. (2022), however, describe that the financial incentives are currently not in focus on enabling CE activities but rather on other forms, such as regulatory incentives. The sustainability manager of interview #1 specifically highlights the need for financial incentives from government stakeholders, rather than incentivizing stakeholders themselves. So, in this case, there might be a slight disagreement between practitioners and theorists. However, they both agree about the necessity of financial incentives for transition to CE but disagree on where the incentives should come from and be placed.

Today, prices are low, making it uneconomical to reuse

Respondent #8 states that the market competition from virgin material is so high that recycled material can't compete. This is supported by the literature

view from Adams et al., (2017): where, numerous construction products have limited value towards the end of their life, making their reuse financially unviable due to their low market value. Adams et al., (2017) additionally states that there needs to be a greater understanding of the cost benefits of applying CE principles to everyone involved.

5.4 Science barriers

Barriers related to knowledge, according to the literature, are specifically related to the lack of information and information diffusion. The knowledge barriers present certain interconnectedness with other barriers, which makes certain barriers more difficult to overcome. For example, a lack of knowledge regarding CE can heavily affect uncertainties, regarding the selection of materials, economic returns, and laws and regulations.

Lack of information

Lack of knowledge

Shooshtarian et al., (2022) concluded that awareness and knowledge are one of the most significant barriers to the transition toward CE. It is additionally presented that there seems to be a lack of knowledge on how to adopt circular principles from actors, suppliers, and governments. Shooshtarian et al. (2022) additionally present that awareness and perception is a major enabler of CE, as it enables R&D and education of stakeholders and provides evidence for the added value CE provides. The interviews, however, present varying awareness and knowledge regarding the CE concept.

Both respondents #1 and #7 expressed the concept of CE being an unexplored ground for them and that it is necessary for the industry to learn more for more circularity within the sector. This presents the lack of knowledge barrier in multiple steps, where barriers of other categories cause challenges related to the transition to circular construction. For example, there's a shortage of knowledge on how the design of buildings can affect

their circularity (Adams et al., 2017). Respondent #8 gave the perspective of technical difficulties which could appear when working with methods that enable circular construction. Indicating a lack of knowledge regarding the simplicity of using circular methods, and when to use such methods.

Information diffusion

Unidentified barriers:

According to respondents there is a narrow understanding of the CE concept, focusing mostly on potential reduction of Co2 rather than other potential benefits such as waste reduction. This narrow understanding has some similarities to other barriers, such as lack of knowledge. However, individuals within the industry have an understanding of the CE concept as a sustainability method focusing on the reduction of CO2 emissions but do not consider the whole CE concept, such as potential economic benefits implying that the information diffusion of the CE concept needs to be examined further.

5.6 Policy barriers

Regulations:

Lack of environmental regulations and laws which is driving the rest of the barriers to the circular economy

Bilal et al. (2020) describe that the lack of environmental regulations and laws is a driver for the other CE barriers. However, in the case of PEAB, it is not necessarily the lack of environmental regulations and laws which is the problem, but rather how inconsistently they are applied, which creates complexity in how to adapt to the laws and regulations on a holistic scale.

Unidentified barriers

From the interviews, two barriers were presented by respondents #3 and #4 in which the authors were unable to find any parallels in the current

literature framework. Respondent #3 responded that there are currently too many environmental regulations that hinder the usability of reusable construction materials, even if the materials are perfectly suitable and easily obtainable for construction purposes. Respondent #4 describes a similar challenge, there are too many laws and regulatory standards on stairs, doors, and other materials that need to be fulfilled for usage in construction. These regulations actively hinder potential reuse. Even if the materials meet current standards, it is impossible to prove without sufficient paperwork and certifications, which is rarely possible when acquiring second-hand construction materials.

As previously mentioned, there are no barriers that could be applied to the barriers respondents #3 and #4 presented. In fact, the barrier ‘’lack of environmental regulations and laws’’ actively contradicts what the practitioners are saying, that there are too many environmental regulations that hinder the reuse of construction materials (Bilal et al., 2020; Shooshtarian et al., 2022). This might imply that current CE literature does not consider too many new environmental regulations as a barrier, or that there might exist other regulations that impede regulations that enable CE. However, it is a clear barrier for the practitioners, specifically from a project manager and site manager perspective.

Ownership:

Lack of legal warranties on recycled or reused materials

Respondents describe that companies are not willing to take the risk of not having documented warranties on the material. For this to be achieved traditional ownership models need to change. And according to construction sector literature traditional ownership models are hard to change. Considering the conservativeness of the construction industry, where operators favor traditional methods and practices with lower technological content, it will possibly create more complications and barriers (Giorgi et al., 2022).

Adams et al. (2017) further argue the need to establish further ownership of reusable material, which can facilitate the creation of necessary documentation, certification, and warranties which can facilitate more reuse of materials. Respondent #4 agrees with this sentiment, stating the need, but also that it is a matter of time before companies reorganize the documentation of careful deconstruction for waste management and sourcing of reusable materials.

5.7 Industry Barriers

Integration

Lack of integration of sustainable waste management and potential reuse

According to Hossain et al. (2020), one of the key challenges of CE is to integrate sustainable waste management and reuse systems. The barrier is further emphasized by Çimen (2021), as there is a need for a standardized information system for an international material bank in order to integrate sustainable waste management for potential reuse successfully.

Respondent #2 illustrates a part of this barrier by describing that they are aware that PEAB currently has a place where they store disassembled materials. However, the individual is unaware of where it is, and there is a general lack of knowledge on how to access the materials therein. This describes both a lack of knowledge and a lack of integration with other CE projects currently in place at PEAB.

Inadequate communication with clients, designers, and subcontractors

According to Hossain et al. (2020), in order to promote CE and facilitate a successful transition, there needs to be in-depth teamwork and consultation between project teams. Respondent #6 expressed inadequate communication as a challenge when working with CE, where, for example, it can sometimes be difficult wanting to get information related to a specific material from subcontractors.

Incentives

Lack of incentives for actors in a supply chain to adopt CE

Currently, due to the many barriers to transitioning toward CE, the actors and entrepreneurs in the construction industry lack the necessary incentives for CE transition. Respondent #4 expressed that a lack of actors can be due to a lack of incentives for actors in the supply chain. Which might be due to entrepreneurs of small to medium companies having small margins, making it not viable to experiment with methods that either will result in a higher cost or more risk.

Infrastructure/Supply chain: Risk and uncertainty

Supply and business risk

Respondent #8 presented the need for a company to stock up and store recycled material and to create a market of reusable material. As there currently does not exist a material market, it is hard for both clients and contractors to work with recycled material. Creating both a supply and business risk when working with CE. This is further described in the literature as the lack of actors can cause a constant supply and a business risk for larger companies when adopting circular construction methods (Hossain et al., 2020)

5.8 Common denominators between interview, literature and observations

When comparing the findings of the literature, observations, and interviews, several opinions, statements and themes were shared.

Lack of documentation and guarantees on reusable construction materials are big barriers to CE transition, being prominent within both literature, the industry seminar and the interviews, being represented by respondent #1, #4

and #5. It was described by respondents that construction enterprises are unwilling to take the risks associated with reusable construction material due to how often they lack documentation and guarantees while also being more expensive than traditionally acquired material. Perspectives which were additionally shared by the industry seminar. But it was also stated that recycling and upcycling makes environmental certifications and guarantees impossible to attain thus there is a need for easier certification of CE material to overcome the barrier.

Within the construction sector, there is a larger push for sustainability, specifically from construction sector actors regarding reduction of CO2 emissions, which serves as a primary reason for transitioning to CE (Parliament, 2021). This push could be observed at PEAB in both their annual report and within their LCA project group, in which it was specifically stated to be a sustainability goal (*PEAB Annual Report*, 2022). Respondent #7 describes that people within PEAB only see circularity as a method for Co2 reduction, however even if something is zero Co2 emissions it can still be bad for the environment in other ways such as in waste creation and resource use. It was additionally described that other benefits of CE were rarely discussed in the industry, benefits that include new revenue streams or waste management benefits (Andersson & Buser, 2022; Korhonen et al., 2018).

The industry seminar additionally presented the need for a marketplace for reused material that all the actors in the industry can use. This need was echoed by several respondents, most notably respondent #3 and #4 but the need for this marketplace was additionally expanded to include a potential industry wide material bank where warehousing, testing, upcycling and transportation of materials could be operationalized. The lack of an international material bank is additionally a barrier stated in the literature (Çimen, 2021). Additionally a material bank or second hand reusable materials market has been proposed in the literature to facilitate material recycling and component reuse, which additionally motivates designing for

deconstruction to source the materials required for the market or bank. It is further stated that continued development in these areas is essential for advancing circular construction practices (Cai & Waldmann, 2019).

6. Conclusions and discussion

This study has examined which barriers hinder the CE transition in a construction firm. The barriers of CE transition were analyzed by how they are perceived by practitioners in the industry and contrasted by how they are perceived by the theorists. The findings of the study led to several conclusions.

- New barriers were identified in the study such as supply and demand issues of reusable materials and environmental regulations effects on reuse practices, which are not covered within the current literature.
- The cautiousness within the construction sector affects the perception and awareness of CE, further limiting the transition. Therefore, firms are less likely to experiment and adjust, which according to industrial transition theory, is required for a socio-technical transition.
- How the barriers to CE transition are interrelated. There is a need to investigate both barriers individually and how they affect other barrier groups.
- A full industrial transition within the construction sector is difficult due to each project being different; LCA can facilitate strategic opportunities for each project and increase awareness and perception of CE within firms.
- Further collaboration within the construction industry is a necessity to reduce associated risks with transition.

6.1 Perception and awareness of CE within the firm

The empirical findings indicated varying levels of awareness and understanding regarding the concept of CE at PEAB. Participants ranged

from having no knowledge or being beginners to focusing primarily on material recycling or expressing concerns about increased regulations. Some respondents had a positive but cautious attitude, emphasizing the need for optimal CE activities based on knowledge rather than blind belief. Lastly, there were participants who demonstrated a comprehensive understanding of circularity, encompassing multiple dimensions such as energy and chemical aspects. However, the general level of understanding is in its early stages, where knowledge is either self-taught or comes from an understanding of how circular principles would affect their work assignments.

Practitioners seem to be cautious of pushing circularity in the industry as firms find it too risky to fully commit to CE transition, instead remaining flexible by training relevant competencies that might be useful when they are ready to commit to a transition. However, industry members are currently experimenting with different pilot projects trying to find circular activities that are both economically and environmentally sustainable. This is additionally supported by the respondents, who said that circularity has merit in the construction sector but must be evidence-based and not act on speculation. This line of thinking might hinder the adjustments and experimentation required for a socio-technical transition (F. W. Geels & Schot, 2007).

The cautious attitude of CE transition can be related to the conservativeness of the industry. This can be observed from the respondents, as there is a mentality of wanting to be second to transition, as there is a certain risk in innovating new business models. However, it was found that a lack of proven business cases underpinned by viable business models is a bigger barrier to CE transition. This is further supported by Adams et al. (2017), stating that a lack of incentives, demand, interest, and conservativeness are influencing factors for the lack of proven business cases of CE within the Construction sector.

There is a large risk for companies to try and experiment with new

innovation processes. The construction sector mostly cares about three dimensions, cost, quality, and time related to their projects; adopting new construction methods and business models is usually good for improving these dimensions. However, CE in the construction sector is currently perceived as expensive and uses materials of questionable qualities that also take more time to source and warehouse. All of these factors make it difficult for the construction sector to justify CE transition and could be a factor that limits the push toward a transition to a circular construction industry that further causes it to be both low and slow.

6.2 Low and slow CE transition due to barriers

Currently, the transition to CE is both low and slow; this can be seen both inside and outside the construction industry, with Sweden only being 3.4 % circular despite presenting one of the most ambitious goals of becoming net-zero by 2045 (Jensen & Stigson, 2022). Reasons for this within the construction industry are for several reasons, such as the pressure of industrial transition is currently not perceived by all industry actors and a lack of knowledge (Chen et al., 2022). All of which can be seen in the empirical findings at PEAB.

Geels & Schot (2007) describes that a circular transition can only happen if system actors perceive and act on landscape pressures. Additionally, it is important to understand that actors within the system are interconnected, resulting in an effort to introduce changes such as CE that will affect all actors. Geels and Schot (2007) argue that the various actors involved in the current industrial system are resistant to change because they have invested a lot of time and money into the current way of doing things. This implies that cumulative adjustments and reorientations are required within the construction sector to establish new ways to facilitate CE that works for all interconnected actors (Chizaryfard, 2023).

From the general interview results, it was found that the push for CE was perceived differently depending on the member within the firm. Certain

respondents described a noticeable push, while others did not feel a push for CE at all. And considering a requirement for industrial transition is that system actors perceive and act on landscape pressures via collaboration, it could be reasoned that external pressure is not felt enough to cause driving changes to occur, showcasing a reason for the slow transition.

It was also found that in the construction industry, there were instances where firm members had conflicting interests or faced challenges due to the interconnectedness of the industry. Respondents described an example of this as being that the municipality demands more circularity and recycled materials; however, various regulations exist specifying different requirements that the material must meet. This misalignment can create barriers for actors seeking to adopt circular principles, causing additional problems for firm members wanting to work with circularity in this case due to a significant portion of the materials available may not meet those requirements.

While it is a challenge to manage the conflicting interests of interconnected construction sector actors, there exist other challenges that can slow down the CE transition. These challenges, often taking the form of barriers, can both be interconnected and complex and is a potential reason why CE transition is both low and slow within the construction sector.

For example, the lack of new standards for the design of circular products and buildings can be related to the conservativeness of the construction industry as the industry tends to stick to traditional methods and practices. The conservativeness of the industry further restricts CE development due to factors such as reducing risk or cost. Thus, there is a hesitancy for project developers and actors to adopt new approaches without clear guidelines or proven business cases. Without standards to promote circular construction in projects, it is, therefore, difficult to incentivize project developers to innovate and adopt circular construction. The lack of standards can additionally increase uncertainty when trying to implement CE into projects, as it may be perceived as an increased risk or cost.

The uncertainty of return on investment is a significant barrier to the sectoral transition towards circular construction. As clients often focus on cost-effectiveness and return on investment when making decisions about construction projects. A connection between the uncertainty of return on investment and scarce interest and demand from clients can therefore be observed where clients may be hesitant to demand or invest in circular construction as it can be perceived as expensive and time-consuming.

It's additionally unclear if clients have enough knowledge of CE, as many clients may not fully grasp the long-term value and positive impacts of circularity on resource efficiency and environmental sustainability. This limited knowledge and awareness can further influence their decision-making process and lead to a lack of demand for circular construction.

Furthermore, the lack of legal warranties, lack of demand from the market, and lack of environmental regulation are also significant interconnected barriers to sectoral transition. Using construction materials without legal warranties and documentation is a significant business risk due to accountability issues. According to the respondents, this is the main reason why construction enterprises are wary of using reusable materials, as it is rare that they have the necessary legal warranties and documentation. To facilitate the use of reusable materials, there is a need to have warranties and documentation on reusable materials, which is especially difficult for upcycled and recycled materials. Therefore, warranties and documentation need to be supported by new environmental regulations that can enable the creation of necessary legal documentation and warranties for reusable construction materials.

In conclusion, two of the major reasons why the transition to CE within the construction sector is low and slow are because of the interconnectedness and differing perceptions between the actors in the construction sector and the interconnectedness and complexities of the CE barriers. Therefore, it's difficult for any single actor to transition towards CE fully, and it's too early

to start working with new business models for existing companies.

However, it was found from the study that respondents who had experience working with circularity found it a positive experience. Where they found it both rewarding and interesting when it worked; however, it was explained as those occurrences were rare as multiple conditions had to be attained in order to facilitate circularity within the projects. The positive experiences of circular business cases lead to many other respondents reporting its positive effects to the authors, which is a sign that successful business cases can help develop an awareness of circularity within firms. This suggests that successful business cases tied to circularity can help develop an awareness of CE within firms, potentially inspiring larger circular business cases.

6.3 Addressing the barriers

Adopting circular principles in the construction industry requires a holistic approach that involves addressing each barrier individually and collectively together with interconnected actors, requiring cumulative adjustments and reorientations. One effective way to address barriers is by raising awareness of circular construction and promoting the adoption of CE activities (Shooshtarian et al., 2022).

This approach is linked to educating stakeholders and reporting evidence for added value from CE, which creates the necessary pressure for actors to transition to circular practices for actors to feel pressure to transition. There are different ways awareness can be raised within the construction sector, Bocken et al. (2015) suggest that industry seminars can be an effective way to build awareness of CE. This activity can currently be observed in the construction industry as Ramboll Buildings held an industry seminar that aimed to spread awareness of the benefits, necessities, barriers, and enablers of circular construction.

An activity PEAB is currently conducting to increase awareness of CE and address barriers is via the LCA project group, which aims to develop

competencies related to calculating the environmental impact a building project has throughout its life cycle. With the aim of identifying strategic paths forward for reducing their environmental impact. This activity is supported by (Xue et al., 2021), who argue that an integrated framework for CE transition with a BIM-based LCA can promote sustainable and circular construction. Due to PEAB aiming to integrate BIM with their LCA calculations within the LCA project, it is reasonable to assume that PEAB is on its way to creating an integrated framework for CE transition that can assist in addressing the barriers.

While the construction industry is currently doing activities that can be interpreted as raising awareness and addressing barriers to CE, it can be speculated that there are more activities that can be conducted to address barriers within the industry.

One approach is to develop further and to valorize the work done through LCA. Creating opportunities for companies to find suitable methods to improve and optimize a construction project. To develop and facilitate the work with LCA, there needs to be increased communication between developers and subcontractors. This involves for subcontractors to provide the necessary information related to material reporting, and facilitating more information related to the building. Together with utilizing supportive tools such as BIM can enable the selection of sustainable materials and methods of construction during the design phase (Hossain et al., 2020).

As previously mentioned, addressing barriers requires a holistic approach that involves addressing barriers individually and collectively together with interconnected actors based on cumulative adjustments and reorientations. This implies that there is a need to increase cooperation between industry actors to address CE barriers.

Increasing cooperation can lead to several activities that could equally benefit construction sector actors. One possible example is that the construction sector and policymakers can collaborate in creating legal

foundations for easier documentation and warranties to protect and enable circular construction practices. Which is addressing the ‘’lack of legal warranties on recycled or reused material’’ barrier (Chen et al., 2022).

Another example where cooperation could be beneficial is in the creation of secondhand material markets for reusable materials in which materials could be warehoused, recycled, upcycled and delivered. Secondhand material markets already exist in limited forms within the construction sector such as the material bank of Varvsstaden and CCbuild. Which is addressing the ‘’The lack of market mechanisms to promote materials recovery and an ineffective process chain for recovering’’ barrier (Giorgi et al., 2022). However, respondents within the study have expressed that while these projects are a good start for addressing CE barriers, specifically supply chain and market barriers, they need to be larger in scope to have wider practicality in construction projects. If construction sector actors collaborate on a potential industry-wide material market, the material market can include a larger quantity and variety of reusable materials. This can allow actors to provide more opportunities to meet the demand of modern construction projects while additionally sharing risks involved.

Collaboration between construction actors can additionally incentivize the transition to circular construction, as circular construction practices need to be made more profitable and attractive to clients. When the costs and risks of new business cases are shared, such as in the case of a potential material bank, construction sector actors might be more willing to experiment and innovate, two factors that are necessary for industrial transition (Chizaryfard, 2023; F. W. Geels & Schot, 2007). As currently, the lack of infrastructure and material market for reuse makes experimenting with circular construction in larger projects more challenging.

6.4 Literature Barriers Compared with Empirical Results: practitioner insights

Based on the coding process of the interviews, most interview quotes that could be interpreted as a barrier had a parallel described in the literature. However, the literature description of all barriers was not always a perfect fit for how the challenges and barriers of adopting CE and CE activities were experienced and described by the practitioners in the interviews.

A key example previously highlighted is the ‘’High uncertainties and risks of a consistent supply of recycled material’’, which is described in the literature as one of the key challenges of adopting CE activities in supply chains (Hossain et al., 2020). However, within the interviews, supply and demand issues are instead highlighted as part of the uncertainty and risks regarding the consistent supply of recycled material but are currently unmentioned in the literature. Therefore the literature definition ignores the supply and demand complexities of reused materials, instead being generalized into ‘’risks and uncertainties of supply’’. Practitioners could benefit by having these key complexities highlighted within the literature to increase further the understanding of the challenges and pitfalls associated with the barriers. Therefore, there is a risk that the barriers are currently too generalized to capture the complexities of the actual challenges the industry is facing regarding CE transition, which limits their practicality to the practitioners who are trying to identify and overcome the barriers.

Additionally, researchers might be underestimating the role they can play in the facilitation of CE within the construction industry, despite their push for it. Within the infrastructure barrier, ‘’Inadequate communication with clients, designers and subcontractors’’ (Hossain et al., 2020) describes that there must be in-depth cooperation between project teams from the conceptual stage to the project conclusion in order to facilitate CE in the construction industry. When compared to the practitioner's perspective, respondents describe that researchers and specialists must be included in order to facilitate work on CE and material reuse. Implying that there are

potential inadequacies in the communication between the construction sector, researchers, and specialists as well.

Additionally, there were challenges and barriers described in the interviews which had no suitable parallels in the literature, which were presented as N/A within the data structure sheet (Table 17). Examples of this are the two barriers in the Regulation subcategory of the Laws and regulations barrier category, which insinuated the same thing. That current environmental regulations and material standards can act as a barrier to the reuse of deconstructed material, as old material might not meet the standards new material has to uphold. This suggests that barriers in the current literature are inadequate in describing all the actual challenges the construction sector is currently facing regarding CE transition in the construction sector and that there is a need for further research on the subject.

6.5 Value chain implications of reuse and circularity

A common challenge firms face are the difficulties in reusing existing resources and capabilities to provide new forms of value, which is something inherently tied to CE activities (Bigelow & Barney, 2020). This has significant implications for construction firms value chains, especially when considering the barriers to CE transition presented in this study.

Several respondents in the study expressed wishes for better infrastructure regarding the procurement of reusable construction materials via having a public online marketplace and periodical transport of leftover and unused material from and to other construction sites. These wishes would require having a constant supply of reusable material readily available via accessible means, which would require a great effort from PEAB to properly adapt their own supply chains for retrieval, storage, and delivery of said material to their construction sites. Therefore, it would additionally require information management systems that would describe what types of materials are stored, material specifics such as certifications, location stored, and amount of material storage.

If the proposed changes are implemented, there might be larger value chain implications if the changes enable a larger industrial transition from the traditional take-make-waste model to a circular model (Fořt & Černý, 2020). As certain materials, such as concrete, can be continuously reused, it places lower stress on other forms of new material acquisition. However, this requires construction firms to continually design for deconstruction of buildings and reuse and recycle materials in order to keep materials in circulation as long as possible, extending material lifespans. Therefore it is a necessity to consider the adaptability and flexibility of the materials at the end of life, making it easier to restart the life cycle, which enables circularity (Adams et al., 2017). All of which is heavily dependent on design professionals to design construction projects for adaptability, flexibility, and deconstruction from the start, enabling circularity (Kibert, 2016; Liu, 2009; Srour et al., 2012; Webster et al., 2005).

Another value chain implication that must be considered when sourcing reusable materials, highlighted by respondents, was the environmental requirements placed on construction sites to source sustainable materials. One way the construction firms enable the sourcing of sustainable materials is via the requirements of certain environmental certifications like ‘’Svanen’’. However, if the construction material has been refurbished, upcycled, recycled, or reused, original environmental certifications might not apply, which could hurt the usability of the circular material. Therefore, construction firms have a need for updated certifications for materials sourced in deconstruction, especially if the construction material had the certification before the refurbishing, recycling, or reuse of it.

The industrial transition towards CE activities will additionally open new revenue streams. Further considering the wishes of respondents regarding enabling circularity via reusable material retrieval, delivery, storage, and the possibility of having a material database and marketplace. These functions could start as internal support for current building projects, they could later be extended to other firms as a form of waste management or material

procurement of reusable material and, thus creating new business areas or markets. Finally, construction firms could additionally open up new revenue streams by refurbishing and repurposing building materials that might not otherwise have been suitable for new construction (Eberhardt et al., 2022). As PEAB is already one of the largest firms in the Nordic construction sector with many subsidiaries such as Swerock, PEAB could create new subsidiaries for these functions.

Considering the fragmented and disjointed nature of the construction sector, enabling partnerships and collaborations are key for the industrial transition to CE in the construction sector (Chen et al., 2022). CE has implications for the entire life cycle of a product, which entails work from actors across the supply chain, from design to construction and from operation to End-of-life management (Korhonen et al., 2018). Thus, there is a need for the construction sector to work more closely and collaborate with suppliers, customers, and stakeholders across the value chain for CE purposes.

6.6 Thesis contributions

6.6.1 Theoretical contribution

As previously highlighted in the introduction, while the barriers to industrial transition have been extensively researched, the barriers to CE transition, particularly within the construction sector, have only recently gained attention despite being a typical case of industrial transition (Hossain et al., 2020). Therefore, exploring the barriers to CE transition in the construction industry has significant theoretical implications for the broader field of industrial transition, by deepening the understanding of barriers within a unique context.

However, there is currently a gap in the literature regarding practitioners' perspectives on the barriers to CE transition within the construction sector. Thus, it is crucial to capture the views of practitioners to fully develop an understanding of the challenges and obstacles they face. By examining the

current perspectives of practitioners, it is possible to deepen the theoretical understanding of barriers and identify practical strategies to address them.

To make a contribution to this area of research, this thesis presents a figure for categorizing the challenges and barriers to CE transition in the construction sector according to regime actors of industrial transition theory (Figure 3). The figure can serve as a tool for easier categorization and analysis of barriers, and it can inform potential future research in this area. Ultimately, a deeper understanding of the barriers to CE transition in the construction industry can facilitate a smoother transition to a more sustainable and CE.

6.6.2 Practical contribution

Research on barriers inherently has practical contributions, as the observation and identification of barriers can be the first step in overcoming them. This study additionally focuses on the practitioner's perspective regarding the industrial transition of CE in the construction sector. This further contributes to the understanding of what barriers the construction sector is currently facing, which has practical implications, mostly for the construction industry but also for similar industries that are considering the industrial transition to CE. Therefore, the findings of the thesis could have applicability to other actors and industries in other countries. Even if the practical implications are not generalizable, there might be some form of transferability between the industries.

Implicitly, in the categorization of barriers in our literature framework, the framework can act as a checklist of barriers to consider when considering CE implementation. This implies that the thesis findings could be practical for managers and project leaders currently in the stage of assessing the risks and benefits of implementing CE or CE activities. Therefore, the research can assist in decision-making processes by being more aware of the challenges and risks involved and will allow practitioners to adjust

strategies accordingly.

The study aims to capture the perspectives of many different types of practitioners, specifically the project-based view, the design-based view, and the construction site-based view. The practical implications are that by looking into the interview results, practitioners can achieve a more holistic view of how the challenges and barriers are experienced and perceived from different perspectives at the firm. This can prepare practitioners for which viewpoints exist in the challenges of CE transition, which can provide opportunities for planning how to navigate the complexities of conflicting viewpoints.

Via the results of the data structure sheet, practitioners can discern the most common barriers to CE transition (Table: 17). This has practical implications for understanding which barriers are perceived to have the biggest impact on slowing down the transition of CE activities.

6.6.3 Limitation

The construction sector is a complex industry with a wide variety of actors. Therefore, we have limited our data collection to a single large actor within the Swedish construction sector. This will allow for a more holistic description of regulations and cultures, which could result in barriers to CE implementation. However, when it comes to the analysis of literature, the authors decided not to limit themselves to Swedish literature, as the Swedish literature on the subject is far too limited to provide a generalized understanding of the construction industry at large.

The biggest limitation faced by this study is the data access of empirical data, as the study is limited to the examination of a singular firm. However, this allowed the study to get a deeper connection with one of the largest actors in the Swedish construction sector, whose representativeness of the larger Swedish construction sector will help illustrate the transferability of findings to the larger construction sector (Bell & Bryman, 2007).

One possible way of providing additional generalizability would be to include additional firms within the data collection. However, the observation of multiple large firms would not necessarily be feasible as projects at large firms generally last longer than a year. At the same time, we only have around six months of time available for research. Therefore the authors found that the duration of the study would be more advantageously spent by deeply examining the data at a firm representative of the larger nordic construction industry rather than aiming for a broad generalization based on findings from a number of smaller firms.

6.7 Suggestions for future research

The topic of industrial transition is a well-researched topic; comparably so, the research on CE, specifically in the construction industry, remains relatively unexplored, therefore, further research is needed (Hossain et al., 2020).

Within the thesis, several challenges and barriers to CE transition within the construction sector were presented that currently do not have any clear parallels within the literature, specifically in regard to supply and demand issues of reusable material and current environmental regulations hindering CE activities rather than facilitating them. One example of this stated by respondents was the ‘’Svanen’’ environmental certification, which was stated to hinder reuse practices even though one aim of the certification was to facilitate CE. Further investigating these new barriers could lead to additional information in overcoming them, therefore benefits exist in researching this literature and research gap further in another study.

Additionally, there exist possibilities for exploring the need for cooperation between construction sector actors to enable CE transition. This is due to several respondents in the study describing that large construction firms need to work together to enable the use of reusable materials to be more practical with potential cooperation on a large material bank being stated as

an example. Research has additionally started to highlight the role an industry wide resource bank or market could play in the facilitation of CE, however research has yet to identify how a material bank or material market could be feasibly created. Further research on this topic could enable more cooperation which could result in more reusable construction materials being available on the market, which could enable circularity within the industry. Therefore, the authors additionally suggest researching previous cooperations between actors in the construction sector and what kind of long-term effect and impact it had, and if further cooperation can lead to wider and faster CE transition.

7. References

Adabre, M. A., Chan, A. P. C., Darko, A., & Hosseini, M. R. (2022). Facilitating a transition to a circular economy in construction projects: Intermediate theoretical models based on the theory of planned behaviour. *Building Research & Information*, *0*(0), Article 0. https://doi.org/10.1080/09613218.2022.2067111

Adams, K. T., Osmani, M., Thorpe, T., & Thornback, J. (2017). Circular economy in construction: Current awareness, challenges and enablers. *Proceedings of the Institution of Civil Engineers - Waste and Resource Management*, *170*(1), Article 1. https://doi.org/10.1680/jwarm.16.00011

Akinade, O. O., & Oyedele, L. O. (2019). Integrating construction supply chains within a circular economy: An ANFIS-based waste analytics system (A-WAS). *Journal of Cleaner Production*, *229*, 863–873. https://doi.org/10.1016/j.jclepro.2019.04.232

Andersson, R., & Buser, M. (2022). *From waste to resource management? Construction and demolition waste management through the lens of institutional work* (No. 6). *40*(6), Article 6. https://doi.org/10.1080/01446193.2022.2081989

Antwi-Afari, P., Ng, S., & Hossain, M. (2021). A review of the circularity gap in the construction industry through scientometric analysis. *Journal of Cleaner Production*, *298*. https://doi.org/10.1016/j.jclepro.2021.126870

Auerbach, C., & Silverstein, L. B. (2003). *Qualitative Data: An Introduction to Coding and Analysis*. NYU Press.

Augenbroe, G., & Pearce, A. (2000). Sustainable construction in the USA: Perspectives to the year 2010. *Proceedings of the Millennium Conference*, 17–25.

Bates, A. (2022, January 20). *Who benefits, and how, from a circular approach to buildings?* Ramboll Group. https://ramboll.com/ingenuity/who-benefits-and-how-from-a-circular-approach-to-buildings

Bell, E., & Bryman, A. (2007). The Ethics of Management Research: An Exploratory Content Analysis. *British Journal of Management*, *18*(1), 63–77. https://doi.org/10.1111/j.1467-8551.2006.00487.x

Bigelow, L., & Barney, J. (2020). What can Strategy Learn from the Business Model Approach? *Journal of Management Studies*, *58*. https://doi.org/10.1111/joms.12579

Bilal, M., Khan, K. I. A., Thaheem, M. J., & Nasir, A. R. (2020). Current state and barriers to the circular economy in the building sector: Towards a mitigation framework. *Journal of Cleaner Production*, *276*, 123250. https://doi.org/10.1016/j.jclepro.2020.123250

Bocken, N. M. P., Rana, P., & Short, S. W. (2015). Value mapping for sustainable business thinking. *Journal of Industrial and Production Engineering*, *32*(1), 67–81. https://doi.org/10.1080/21681015.2014.1000399

Buyle, M., Braet, J., & Audenaert, A. (2013). Life cycle assessment in the construction sector: A review. *Renewable and Sustainable Energy Reviews*, *26*, 379–388. https://doi.org/10.1016/j.rser.2013.05.001

Cai, G., & Waldmann, D. (2019). A material and component bank to facilitate material recycling and component reuse for a sustainable construction: Concept and preliminary study. *Clean Technologies and Environmental Policy*, *21*, 2015–2032. https://doi.org/10.1007/s10098-019-01758-1

Cavalliere, C., Habert, G., Dell'Osso, G. R., & Hollberg, A. (2019). Continuous BIM-based assessment of embodied environmental impacts throughout the design process. *Journal of Cleaner Production*, *211*, 941–952. https://doi.org/10.1016/j.jclepro.2018.11.247

Chen, Q., Feng, H., & Garcia de Soto, B. (2022). Revamping construction supply chain processes with circular economy strategies: A systematic literature review. *Journal of Cleaner Production*, *335*, 130240. https://doi.org/10.1016/j.jclepro.2021.130240

Chizaryfard, A. (2023). *The Industrial TransformationTowards the Circular Economy: Dynamics, Drivers and Constraints*. https://urn.kb.se/resolve?urn=urn:nbn:se:kth:diva-323325

Çimen, Ö. (2021). Construction and built environment in circular economy: A comprehensive literature review. *Journal of Cleaner Production*, *305*, 127180.

https://doi.org/10.1016/j.jclepro.2021.127180

Eberhardt, L. C. M., Birkved, M., & Birgisdottir, H. (2022). Building design and construction strategies for a circular economy. *Architectural Engineering and Design Management*, *18*(2), 93–113. https://doi.org/10.1080/17452007.2020.1781588

Ellen MacArthur Foundation. (2021). The Business Opportunity of a Circular Economy. In L. Liu & S. Ramakrishna (Eds.), *An Introduction to Circular Economy* (pp. 397–417). Springer. https://doi.org/10.1007/978-981-15-8510-4_20

Finkbeiner, M., Inaba, A., Tan, R., Christiansen, K., & Klüppel, H.-J. (2006). The New International Standards for Life Cycle Assessment: ISO 14040 and ISO 14044. *The International Journal of Life Cycle Assessment*, *11*(2), 80–85. https://doi.org/10.1065/lca2006.02.002

Flack, M., Redmo, M., Gränsbo, C., & Ekelund, N. (2023, August 2). *Circular Business Models, Nordic opportunities and challenges in the new geopolitical landscape* [Https://pub.norden.org/temanord2023-507/]. https://pub.norden.org/temanord2023-507/temanord2023-507.pdf

Fořt, J., & Černý, R. (2020). Transition to circular economy in the construction industry: Environmental aspects of waste brick recycling scenarios. *Waste Management*, *118*, 510–520. https://doi.org/10.1016/j.wasman.2020.09.004

Geels, F. (2006). Multi-Level Perspective on System Innovation: Relevance for Industrial Transformation. In *Understanding Industrial Transformation: Views from Different Disciplines* (pp. 163–186). https://doi.org/10.1007/1-4020-4418-6_9

Geels, F. W. (2002). Technological transitions as evolutionary reconfiguration processes: A multi-level perspective and a case-study. *Research Policy*, *31*(8), 1257–1274. https://doi.org/10.1016/S0048-7333(02)00062-8

Geels, F. W., & Schot, J. (2007). Typology of sociotechnical transition pathways. *Research Policy*, *36*(3), 399–417.

Ghufran, M., Khan, K. I. A., Ullah, F., Nasir, A., Alahmadi, A., Alzaed, A., & Alwetaishi, M. (2022). Circular Economy in the Construction Industry: A Step towards Sustainable Development. *Buildings*, *12*, 1004.

https://doi.org/10.3390/buildings12071004

Giorgi, S., Lavagna, M., Wang, K., Osmani, M., Liu, G., & Campioli, A. (2022). Drivers and barriers towards circular economy in the building sector: Stakeholder interviews and analysis of five European countries policies and practices. *Journal of Cleaner Production*, *336*, 130395. https://doi.org/10.1016/j.jclepro.2022.130395

Goteborg stad. (2020). *Dags att bygga och riva cirkulärt! Slutrapport från projektet Upphandlingskrav för cirkulära flöden i bygg- och rivningsprocessen*. https://goteborg.se/wps/wcm/connect/d0600675-8e9c-4522-9984-4783c65d9a07/Slutrapport+Upphandlingskrav+f%C3%B6r+cirkul%C3%A4ra+fl%C3%B6den+i+bygg-+och+rivningsprocessen.pdf?MOD=AJPERES

Goteborg stad. (2021, 26). *Storstadsöverenskommelse för cirkulärt byggande 2030 Slutrapport från förstudie 2020*. https://goteborg.se/wps/wcm/connect/e158ce22-d7f1-46d9-9d5e-69cd45709b06/Slutrapport+Storstads%C3%B6verenskommelse+f%C3%B6r+cirkul%C3%A4rt+byggande_f%C3%B6rstudie+%28002%29.pdf?MOD=AJPERES

Guinee, J. B. (2002). Handbook on life cycle assessment operational guide to the ISO standards. *The International Journal of Life Cycle Assessment*, *7*(5), 311–313. https://doi.org/10.1007/BF02978897

Hossain, Md. U., Ng, S. T., Antwi-Afari, P., & Amor, B. (2020). Circular economy and the construction industry: Existing trends, challenges and prospective framework for sustainable construction. *Renewable and Sustainable Energy Reviews*, *130*, 109948. https://doi.org/10.1016/j.rser.2020.109948

Jensen, Carl, & Stigson, P. (2022). *CGR Sweden*. https://www.circularity-gap.world/sweden

Kärrholm, M. (2014). Stortorget: Ett torg i förändring. *Planering i Malmö : information från Malmö stadsbyggnadskontor*, *2*, 23–23.

Kibert, C. J. (2016). *Sustainable Construction: Green Building Design and Delivery*. John Wiley & Sons.

Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. *Resources Conservation and Recycling*, *127*, 221–232.

https://doi.org/10.1016/j.resconrec.2017.09.005

Korhonen, J., Honkasalo, A., & Seppälä, J. (2018). Circular Economy: The Concept and its Limitations. *Ecological Economics*, *143*, 37–46. https://doi.org/10.1016/j.ecolecon.2017.06.041

Linder, M., & Williander, M. (2017). Circular Business Model Innovation: Inherent Uncertainties. *Business Strategy and the Environment*, *26*(2), 182–196. https://doi.org/10.1002/bse.1906

Liu, L. (2009). *TRACKING THE LIFE CYCLE OF CONSTRUCTION STEEL: THE DEVELOPMENT OF A RESOURCE LOOP*.

Mhatre, P., Panchal, R., Singh, A., & Bibyan, S. (2021). A systematic literature review on the circular economy initiatives in the European Union. *Sustainable Production and Consumption*, *26*, 187–202. https://doi.org/10.1016/j.spc.2020.09.008

Nasir, M. H. A., Genovese, A., Acquaye, A. A., Koh, S. C. L., & Yamoah, F. (2017). Comparing linear and circular supply chains: A case study from the construction industry. *International Journal of Production Economics*, *183*, 443–457. https://doi.org/10.1016/j.ijpe.2016.06.008

Parliament, E. (2021, October 2). *Circular economy: MEPs call for tighter EU consumption and recycling rules | News | European Parliament*. https://www.europarl.europa.eu/news/en/press-room/20210204IPR97114/circular-economy-meps-call-for-tighter-eu-consumption-and-recycling-rules

Parliament, E. (2023, Summer). *Strategy for a Sustainable Built Environment | Legislative Train Schedule*. European Parliament. https://www.europarl.europa.eu/legislative-train/theme-a-european-green-deal/file-strategy-for-a-sustainable-built-environment

PEAB Annual report. (2022). https://peab.inpublix.com/q4-2022/en/

Pomponi, F., & Moncaster, A. (2017). Circular economy for the built environment: A research framework. *Journal of Cleaner Production*, *143*, 710–718. https://doi.org/10.1016/j.jclepro.2016.12.055

Regeringskansliet, R. och. (2023, January 31). *Cirkulär ekonomi—Strategi för omställningen i Sverige* [Text]. Regeringskansliet; Regeringen och

Regeringskansliet. https://www.regeringen.se/rapporter/2023/01/strategi-for-cirkular-ekonomi/

Rios, F. C., Chong, W. K., & Grau, D. (2015). Design for Disassembly and Deconstruction—Challenges and Opportunities. *Procedia Engineering*, *118*, 1296–1304. https://doi.org/10.1016/j.proeng.2015.08.485

Shooshtarian, S., Hosseini, M. R., Kocaturk, T., Arnel, T., & T. Garofano, N. (2022). Circular economy in the Australian AEC industry: Investigation of barriers and enablers. *Building Research & Information*, *0*(0), Article 0. https://doi.org/10.1080/09613218.2022.2099788

Singh, A., Berghorn, G., Joshi, S., & Syal, M. (2011). Review of Life-Cycle Assessment Applications in Building Construction. *Journal of Architectural Engineering*, *17*(1), 15–23. https://doi.org/10.1061/(ASCE)AE.1943-5568.0000026

Srour, I., Chong, W., & Zhang, F. (2012). Sustainable recycling approach: An understanding of designers' and contractors' recycling responsibilities throughout the life cycle of buildings in two US cities. *Sustainable Development - SUSTAIN DEV*, *20*. https://doi.org/10.1002/sd.493

Tornkvist, A. (2015). *Arvet från Varvet—En kritisk granskning av Varvsstadens industriella kulturarv*. http://lup.lub.lu.se/student-papers/record/4934054

Velenturf, A. P. M., & Purnell, P. (2021). Principles for a sustainable circular economy. *Sustainable Production and Consumption*, *27*, 1437–1457. https://doi.org/10.1016/j.spc.2021.02.018

Vrijhoef, R. (2008). *A Critical Review of Construction as a Project-based Industry: Identifying Paths Towards a Project-independent Approach to Construction*. https://www.semanticscholar.org/paper/A-Critical-Review-of-Construction-as-a-Industry-%3A-a-Vrijhoef/21d16a257b4e2f15780955c36023995648430ecd

Webster, M. D., Gumpertz, S., & Costello, D. (2005). *Designing Structural Systems for Deconstruction: How to Extend a New Building's Useful Life and Prevent it from Going to Waste When the End Finally Comes*. https://www.semanticscholar.org/paper/Designing-Structural-Systems-for-Deconstruction%3A-to-Webster-

Gumpertz/b793263399b9badcb165a4f71588a68a82a69ccd

Xue, K., Hossain, M. U., Liu, M., Ma, M., Zhang, Y., Hu, M., Chen, X., & Cao, G. (2021). BIM Integrated LCA for Promoting Circular Economy towards Sustainable Construction: An Analytical Review. *Sustainability*, *13*(3), Article 3. https://doi.org/10.3390/su13031310

Yin, R. K. (2015). *Qualitative Research from Start to Finish*. Guilford Publications.

Zabalza Bribián, I., Aranda Usón, A., & Scarpellini, S. (2009). Life cycle assessment in buildings: State-of-the-art and simplified LCA methodology as a complement for building certification. *Building and Environment*, *44*(12), 2510–2520. https://doi.org/10.1016/j.buildenv.2009.05.001

Zandee, D., Zutshi, A., Creed, A., & Nijhof, A. (2022). Aiming for bullseye: A novel gameplan for circular economy in the construction industry. *Engineering, Construction and Architectural Management*, *ahead-of-print*(ahead-of-print), Article ahead-of-print. https://doi.org/10.1108/ECAM-03-2022-0288

Appendices

Appendix 1: Swedish and English interview guide

Svenska intervjufrågor

Introduktion

• Hälsningar och syfte med intervjun, börja inspelningen.

• Datahantering och information om inspelning.

o Informera intervjuobjektet hur data kommer att hanteras och deras anonymitet.

o Informera intervjuobjektet att de kan välja att inte svara på någon fråga.

o Informera intervjuobjektet om sekretess och att informationen inte kommer att lämnas vidare.

o Informera om transkribering och möjligheter för intervjuobjektet att granska dessa i efterhand.

• Förväntad tidsram (30min - 1 timme).

• Ytterligare frågor innan intervjun påbörjas?

Formaliteter

A. Vad är din titel och vad är dina arbetsuppgifter?

B. Vad tänker du när du hör cirkulär konstruktion/cirkulär ekonomi?

Frågor projektarbetare:

1: Hur ser du PEABs nuvarande arbete med hållbarhet/cirkularitet?

A. Vad tror du motiverar PEAB att arbeta med hållbarhet/cirkularitet?
B. Finner du cirkularitet viktigt i ditt arbete?

2: Vad tror du är faktorerna som kan bromsa PEABs arbete för hållbarhet/cirkularitet?

A. Vilka nuvarande problem problem existerar i övergången till hållbar/cirkulär verksamhet?

3: Hur tror du att arbetet med hållbarhet/cirkularitet kommer att påverka PEABs arbetssätt?

A. Vilka problem tror du kan uppstå vid övergången mellan arbetssätt?
B. Har sådana förändringar påverkat ditt arbete/roll på företaget? Har du något exempel på det?

Övergång: Vi är intresserade i att se vilka möjligheter det finns att cirkulera in material och byggnadselement in i flödet igen vid rivning.

4: Därför undrar vi om hur du tänker kring möjligheten att återbruka material och byggnadselement i dina projekt idag?

A. Finns det några problem relaterade till det?
B. vad tror du är anledningen att det inte görs oftare?

5. Finns det något sista som du skulle vilja tillägga?

Frågor kommun/regering

1: Hur ser du på byggindustrins nuvarande arbete med hållbarhet/cirkularitet?

A. Vad tror du motiverar dem att arbeta med hållbarhet/cirkularitet?
B. Vad tror du kan avmotivera dem från att arbeta med cirkuläritet

2: Vad tror du är faktorerna som kan bromsa Byggnadssektorns arbete för hållbarhet/cirkularitet?

Vilka nuvarande problem problem existerar i övergången till hållbar/cirkulär verksamhet?

3: Hur tror du ökad fokus på cirkularitet hos byggföretag kommer påverka samarbeten och upphandlingar?

A. Vilka problem tror du kan uppstå på grund av detta?
B. Hur väger ni cirkularitet i era upphandlingar?

Övergång: Vi är intresserade i att se vilka möjligheter det finns att cirkulera in material och byggnadselement in i flödet igen vid rivning.

4: Vad tycker du om möjligheten att återanvända material som samlats in från rivna byggnader i nya byggprojekt?

A. Vad tror du det finns för problem som kan skapas med mer återbruk?
B. Vad tror du är anledningen till att det inte görs oftare?

5. Finns det något sista som du skulle vilja tillägga?

Frågor platschef

1: Hur ser du PEABs nuvarande arbete med hållbarhet/cirkularitet?

A. Vad tror du motiverar PEAB att arbeta med hållbarhet/cirkularitet?
B. Finner du cirkularitet viktigt i ditt arbete?

2: Vad för problem ser du finns med att arbeta med återbruk i din roll?

A. Vad för stöd hade du behövt för att möjliggöra arbete med återbruk?

3: Hur skulle miljö/återbrukskrav påverka ert arbete i nuläget?

A. Hur påverkar det ert samarbete med underentreprenörer?
B. Finns det något som underlättar ditt arbete för att nå miljökrav?

Övergång: Vi är intresserade i att se vilka möjligheter det finns att cirkulera in material och byggnadselement in i flödet igen vid rivning.

4: Därför undrar vi om hur du tänker kring möjligheten att återbruka material och byggnadselement i dina projekt idag?

A. Finns det tekniska problem som påverkar möjligheten att montera ner och återbruka material?
B. Vad för stöd hade du behövt för att möjliggöra ett större återbruk av material från dina projekt.

5. Finns det något sista som du skulle vilja tillägga?

Frågor projektutvecklare:

1: Hur ser du PEABs nuvarande arbete med hållbarhet/cirkularitet?

A. Vad tror du motiverar PEAB att arbeta med hållbarhet/cirkularitet?

2: Vad tror du är faktorerna som kan bromsa PEABs arbete för hållbarhet/cirkularitet?

A. Vilka nuvarande problem existerar i övergången till hållbar/cirkulär verksamhet?

3: Vilka är de största problemen för er på projektutveckling att jobba med cirkuläritet?

A. Vad hade du behövt för att arbeta med det?

Övergång: Vi är intresserade i att se vilka möjligheter det finns att cirkulera in material och byggnadselement in i flödet igen vid rivning.

4: Därför undrar vi om hur du tänker kring möjligheten att planera för att arbeta med demontering i tidigt skede?

A. Vad för problem finns det idag kring att arbeta med det?

5. Finns det något sista som du skulle vilja tillägga?

English interview questions

Introduction

• Greetings and purpose of interview, start recording.

• Data management and information on recording.

o Inform the interviewee how the data will be handled and anonymity.

o Inform the interviewee that they can decline to answer any question.

o Inform the interviewee of confidentiality and will not pass information on.

o Inform of transcribing and possibilities for interviewee to review these.

• Expected timeframe (30min - 1hour).

• Further questions before starting the interview?

Formalities

A. What is your title and what are your work responsibilities?

B. What are your opinions on the concept of Circular construction/Circular economy/?

Questions project worker:

1: How do you see PEAB currently working with sustainability/circularity

A. What do you think motivates PEAB to work with circularity/sustainability
B. Do you find circularity important within your work?

2: What do you think are the factors that might slow down PEABs work with sustainability/Circularity

A. What are the current problems that might hinder transition to sustainable/circular activity?

3: How do you think the work on sustainability/circularity will affect PEABs business operations?

A. What problems do you think might arise when transitioning between work procedures?
B. Have such changes affected your work/role at the company? Do you have examples of this?

Transition: We are interested in seeing what opportunities there are in circulating building material into the material flow again at the time of demolition.

4: Therefore we wonder about how you feel about the possibility of reusing materials and building elements within your current projects.

A. Are there any problems related to that?
B. What do you think is the reason why it is not conducted more often

5. Is there anything else you want to add?

Questions region/government

1: What does the construction sector's work on sustainability/circularity currently look like?

A. What do you think motivates them to work with sustainability/circularity?
B. What do you think might demotivate them from working with circularity?

2: What do you think are the factors which might slow down the construction sectors work for sustainability/circularity?
3: How do you think increased focus on circularity at construction firms will affect cooperation and procurement?

A. What problems might arise because of this?
B. How is circularity currently weighted in procurement processes?

Transition: We are interested in seeing what opportunities there are in circulating building material into the material flow again at the time of demolition.
4: Therefore we wonder about how you feel about the possibility of reusing materials and building elements within your current projects.

C. Are there any problems related to that?
D. What do you think is the reason why it is not conducted more often

5. Is there anything else you want to add?

Questions site manager:

1: How do you see PEAB's current work with sustainability/circularity?

A. What do you think motivates PEAB to work with sustainability/circularity?

2: What problems do you see with working with recycling in your role?

A. What kind of support did you need to enable work with recycling?

3: How would an environmental/recycling requirement affect your work at the moment?

A. How does it affect your cooperation with subcontractors?
B. Is there anything that facilitates your work to meet environmental requirements?

Transition: We are interested in seeing what opportunities there are in circulating building material into the material flow again at the time of demolition.
4: Therefore we wonder about how you feel about the possibility of reusing materials and building elements within your current projects.

A. Are there technical problems that affect the ability to disassemble and reuse materials?
B. What kind of support would you have needed to enable greater reuse of materials from your projects.

5. Is there anything else you want to add?

Questions project developer:

1: How do you see PEAB's current work with sustainability/circularity?

A. What do you think motivates PEAB to work with sustainability/circularity?

2: What do you think are the factors that can slow down PEAB's work for sustainability/circularity?

A. What current problems exist in the transition to sustainable/circular operations?

3: What are the biggest problems for you in project development working with circularity?

A. What would you need to facilitate working with it?

Transition: We are interested in seeing what opportunities there are in circulating building material into the material flow again at the time of demolition.

4: Therefore, we wonder how you think about the possibility of planning to work with dismantling at an early stage?

A. What kind of problems are there today around working with it?

5. Is there anything else you want to add?

Appendix 2: Data structure

Culture

Barrier category and subcategory		Quote	Data source(s)	Secondary data and literature view.	Analysis
Culture and Norms: Interest	Scarce interest and demand from clients	"As a client you want to add as little requriments as possible on contracts to keep the price as low as possible"	Interview #2: Project manager	(Andersson & Buser, 2022): "In practice, the potential for reducing Construction and Demolition Waste (CDW) is yet to be achieved. In particular, it seems that most of the construction companies have not yet reached the expected level of reuse or recycling. Studies have identified a number of barriers to explain this failure, such as scarce interest and demand from clients."	Scarce intrest and demand from clients affect the adoption of CE since if they believe that price will be increased if they place demands on their contectors. This also related to incentives, and unclear financial case, as its not worth for project managers to adopt things they wont get paid for.
		"reducing CO2 emissions are difficult to motivate clients to invest in, as they dont have pay more if they create more emissions"	Interview #6 Technical energy specialist		Clients are more intreseted in reducing their own cost, and would rather invest into options that reduce their energy usage than their CO2 emissions. The effect on climate is a sustaianble question, however there seem to be a lack of interest related to that.
Barrier category and subcategory	Barrier	Quote	Data source(s)	Secondary data and literature view.	Analysis
Culture and Norms: Attitude	The conservativeness of the building industry	"Everything which is new is difficult and experienced as expensive in the construction industry"	Interview #2: Project manager	(Giorgi et al., 2022): "The construction sector is resistant to change towards circularity, as operators tend to prefer traditional practices, with a low technological content."	The interviewees attitude that organisations act in a traditional way strenghen a lot of barriers when wanting to adopt a new innovations. A traditional view affect highligts other barriers, such as "short-term thinking" "scarce intrest and demand from clients" "low acceptance of ideas" Even if the innovation is proven or needed, there seem to always be a resictance to the adoption.
		'I am curious about the circular economy concept. However, the industry is very conservative and therefore things are the same as they usually are"	Interview #3: Site manager		Respondents attitude is in agreement with the literature.
		"compared to other industries, i think the construction industry is a little conservative, but there is happening stuff"	Interview #6 Technical energy specialist		This quote expresses similar opinion as previous intreviewes
	The social dimension of construction	"Theres a need to create building in a timeless architecture, currently we tear down buildings after thrity years"	Interview #8, Construction manager	(Çimen, 2021): "The three targets of CE to improve resource flows, including slowing (through the design of long-life products or prolonged product service life), closing (through recycling and reusing materials for new purposes), and narrowing (through reducing the material requirements for making products) resource loops. In light of this, the construction sector has strived to improve its value chain towards similar CE targets; slowing resource use by prolonging the building lifetime, closing the resource loop through diverting the End-of-Life (EoL) building materials from landfills; and narrowing resource use through improved construction and design efficiency."	There doesnt seem to be any correlation to this statement related to CE. However, by constructing in a timeless architecture that exist for more than 50 years, the effect constrcution has on nature from its life time will be very small. This is in line with one of three strategies for CE in Construction, Slowing

Technology

Barrier category and subcategory	Barrier	Quote	Data source(s)	Secondary data and literature view.	Analysis
Technology: Material	The existing building stock, which has not been designed for circularity	'Materials used 15 years ago might not be able to be used today due to changing material demands and standards"	Interview #3: Site manager	(Adams et al., 2017): "To enable an increased circularity of materials at their highest possible value, technical challenges will need to be overcome. These challenges may present themselves at the material, product and/or building level. This is a principal issue for the existing building stock, which has not been designed for circularity."	Within the current literature set, there is no barrier which describes the uncertainties of the shifting demands placed on the material. The: Using finitely recyclable construction materials (Mahpour, 2018) might be the closest barrier Might imply a research gap.
		'To reuse a working 50-year-old door; you need to take functionalities such as fire- and sound resistance or a specific size for wheelchairs to pass. Technically the door works, but due to a change in standards, the door cannot be used today."	Interview #4: project manager infrastructure		There are issues related to waste hierarchy presented within the current quote.
		'Deconstruction is currently not considered in construction sites, Sweden uses alot of soldering and welding on steel beams for example, which compared to the UK which uses alot of screws instead, makes it more difficult to reuse"	Interview #5: group manager energy and climate		Respondent describes another facet regarding current material stock not being designed for circularity, specifically design for construction. This challenge is represented both in at a material level and on a building level, creating parallells with literature. Lack of planning regarding deconstruction could possibly a new barrier too however.
		I have previously only focused on the operational phase, reducing energy use, but now we have come so far down that the question is, should we really have such thick walls or not?When you haven't looked at energy consumption and such to build the house, maybe you shouldn't have so much insulation. Insulation may have a worse climate impact than what you save.	Interview #6 Technical energy specialist		Shares similar views with literature: that when reaching requirements there are no incentives to continue improving.
		"currently the construction of buildings are done with welding or concrete with reinforcements stubs, making it difficult to deconstruct due to most of the material or building elemets breaking. Theres a need to construction building using deconstruteble methods, using bolts"	Interview #8, Construction manager		Current construction methods are not suitible to deconstruct
		"the problem is from extra demands from customers or architects that make construction use those methods,	Interview #8, Construction manager		

	Other design challenges include the durability of recycled materials	"theres a need to know what type of material you have, if the material has been exposed to fatigue loads, because you cant use it if it has.	Interview #8, Construction manager	(Zandee et al,. 2022) "With the emerging understanding in CE, raw material and waste are now considered equally important resources for both new construction and renovation. While composite materials are investigated from the points of durability enhancement and environmental impact minimization, alternative materials with improved deconstructability and adaptability contribute to circularity."	The durability of resued material is one of the biggest challenges that was experienced by the interviewees. All related to the current unknown of the current satate of the material. Which affect warranties, or noice and fire demands. The material needs to be able to meet those demands, and if its recycled its not clear if it does, magnifing barriers related to demand.
Barrier category and subcategory	Barrier	Quote	Data source(s)	Secondary data and literature view.	Analysis
Technology: Tools and processes	Lack of tools and guidelines for the design of circular products and buildings	"There need to be directives to study in detail on how to prepare building for circularity, with standardized guidlines couldve helped"	Interview #2: Project manager	(Hossain et al., 2020): "in order to promote CE in the construction industry there must be an indepth team work and consultation from the conceptual stage, which is where theres a lack of tools and guidelines for the design of circular products and buidlings."	The quote from the intreviewee is in acordance to hossains idea of barriers towards the implementation of circular buildings. There need to be some standardization to facilitate working with CE.
		'Current calculations does not consider the specifics of the product, only the cost, so when calculating the cost of a roof for example it is impossible for us to tell the specifics of the products" "this causes information management issues, between parties, is easily solvable but creates additional work"	Interview #5: group manager energy and climate	(Hossain et al., 2020): "In addition to economic uncertainty, constant supply and business risk, and lack of tools and guidelines for the design of circular products and buildings, the uncertainty related to reusing materials after their end-of-life is one of the biggest challenges of CE implementation [77]."	While the respondent is speaking from the perspective of their role, current material calculations does not report enough material specification, which can hinder reuse and only place a focus on cost. Respondent #5 have previously described difficulties in material reporting previously
		'We need to find applicable tools that enable us to work more with circularity"	Interview #7: Head of sustainability		This quote was specifically brought up in combination with work regarding Co2 reducation and waste management
		"There are demands to be met when working with warranties, you do what you have to meet those requirments, nothing more, when asked why we dont do more, for example why dont we add solarpannels to the roofs was due to were already reaching the goals and theres no need"	Interview #6 Technical energy specialist		
	The lack of market mechanisms to promote materials recovery and an ineffective process chain for recovering	'We would like support in picking up and procuring remaining material from building sites, it is way easier and cheaper to get rid of material by throwing away than any other way, and a material recovery vehicle could solve that issue"	Interview #3: Site manager	(Giorgi et al., 2022): However, there are still few studies on the identification of CE barriers and drivers considering the building sector (Bilal et al. 2020). Mahpour (2018), Liu et al. (2021) and Adams et al. (2017) analysed barriers and drivers within the management of CDW, identifying mainly the lack of market mechanisms to promote materials recovery and an ineffective process chain for recovering.	Material recovery and an effective process chain is descrbed as a main barrier to CE within the construction sector, having an ineffective process chain is additionally supported by respondent saying that it easier to get rid of the material than recover it in another way. Barrier and quote are consistent with each other.
	Lack of a standardized information system about an international resource bank	"There is value in working with recycling within an organization. However, there are uncertianties working between companies, as its costly to keep and store recycled material that someone might need in the future"	Interview #2: Project manager	(Nasir et al., 2017): the development of CE, new challenges emerges, such as tracking material stock and flow, along with the information which need to be stored in a standardized resource bank.	The resource bank can act as a market for companies which can be argued for the lack of a standardized information system about an international resource bank for companies to use.

Barrier category and subcategory	Barrier	Quote	Data source(s)	Secondary data and literature view.	Analysis
Technology: Complexity	Challenges such as tracking material stock and flow.	'I would like to see some kind of database of avaliable reusable material, we dont know what kind of material we currently have and where"	Interview #3: Site manager	(Çimen, 2021): "With the emerging understanding in CE, raw material and waste are now considered equally important resources for both new construction and renovation. While composite materials are investigated from the points of durability enhancement and environmental impact minimization, alternative materials with improved deconstructability and adaptability contribute to circularity. This brings new challenges such as tracking material stock and flow along with the information to be stored in an internationally standardized resource bank"	Respondent would like a database in which one can track recycled material, which might help enable more usage of recycled or reused material. There is an wish for the respondent to overcome the barrier, as described by Cimen. There is a clear agreement between author and respondent. Consistent with literature
	Complexity of the supply chain	"Each step in the supply chain can act as a barrier for circular construction"	Interview #4: project manager infrastructure	(Chen et al,. 2022): ''The starting point to adopt the circular construction approach is to understand the construction supply chain and how its needs and challenges match the potential of circular construction approach a construction supply chain process consists of multiple functions across its project lifecycle. From a whole life cycle perspective, it includes the phases of Design, Manufacturing (or Production), Construction (or Installation), Maintenance, Operation, and EoL (Deconstruction or Demolition. In practice, the complex interdependence of these multiple participants has limited the participants' capabilities of tracking the building and material information throughout the different phases."	Being able to work with circular construction today, there is a need for all the phases line up. Currently Varvstaden has succeded in the where, the real estate, owner, and developer was the same. Allowing the to developer to hire their own demolitioner. Creating a connection between the complex interdependdce of the multple participants, allowing the to track the building and material information throughout the different phases.
	geographical differences	"When wanting to work with recycled material, theres a complexity in obtaining material, where to find it, then there will be a need to research and evaluate the material, then transporting it"	Interview #4: project manager infrastructure	(Hossain et al,. 2020): ''Sustainable sourcing and supply chain of materials and products should be at the core, as this may significantly influence the environmental impacts due to transport related impacts. ''	Geographical differences was stated my the literature when discussing sourcing material. However, when looked closer there was little to no information on the difficulty of geographical differences related reused material. Nasir present that despite the increased transportation for a circular supply chain there is a lower co2 emissions than sorucing virgin resources. Hossain et al, specifies that sustainable sourcing and supply chain of materials and porducts should be at the cose as this may signigicantly influence the environmental impacts due to transport related impacts. However, there seem to be a lack of awareness that theres a difficulty in obtaining the material, due to geographical differences. As currently theres a difficulty in evaluating reused material, and the cost of both CO2* and money to transport material
		One of the barriers to reuse of construction materials is that if it is justifiable in environmenttal impacts. If an material has to be transported from Malmö to Norrland for construction, it can be difficult to justify that.	Interview #7: Head of sustainability		Respondent brings up an interesting point that Reuse must be justifiable environmentally. The literature supports this by saying that sustainable supplying of materials and products need to be at the core, even with potential gains of reuse. Even if it is a gain in waste reduction it might be a loss in Co2 emissions.

	Challenges such as tracking material stock and flow.	Projektdevelopment and design need to be done in early stages, with up to 2 years before condstruction, where you need to decide on material early, and with reused material there is a difficulty related to obtaining correct material at the right time, if you dont want to house the material up to 2 years"	Interview #4: project manager infrastructure	(Chen et al,. 2022): "The whole life cycle of the buildings needs multiple project participants from the design phase to the EoL phase. Besides the policymakers and investors, the major project participants involved in a circular process-based supply chain network include the project owners, the architects and engineers, the construction contractors and subcontractors, the facility managers, the suppliers and distributors, and the recycling plants. In practice, the complex interdependence of these multiple participants has limited the participants' capabilities of tracking the building and material information throughout the different phases"	Chen et al expresses the difficulty and complexity with working in the construction industry with its multiple actors, where theres an complex interdependence between the actors. Together with what the interviewee expressed the need to choose material early, both the vision communication might be lost.

Market

Barrier category and subcategory	Barrier	Quote	Data source(s)	Secondary data and literature view.	Discussion
Market: Uncertainty	Unclear financial case	'Currently it is difficult to see circularity and re-use of materials as profitable"	Interview #1: Sustainability manager project development	(Adams et al., 2017): "The need to articulate the value aspects of the circular economy was viewed as paramount during the breakout sessions and the ability to measure the value of a product/material across its life cycle There was a common thread of the cost benefit for each party adopting the circular economy not being fully understoodand a general perception that the initial investor may not benefit. Cost and associated profit was seen to be the dominantfactor in any decision-making process which can be compounded by the short-termism of many clients."	The quote seems to be in the direct agreement with Adams quote, especially the part with cost benefit not being fully understood. However in this part our interviewee said it was difficult to see the profitability, not difficult to understand, they even described that Re-use and circularity is a necesisty for the future.
		'There is more new construction than demoliton, and according to economics low supply can lead to higher cost. That in addition to the need for warehousing the materials, which might need the creation of a new firm within PEAB to do, meaning further higher costs which will make it difficult to make reuse of materials profitable."	Interview #5: group manager energy and climate		The respondent describes that there would be a need to set up a new firm for the management of resuable materials, something the respondent considers too costly to be profitable.
	Uncertainty about the return on investments	'I dont think potential reuse would result in saving money, i think the environmental aspect is the big benefit."	Interview #3: Site manager	(Shooshtarian et al., 2022): "the top three barriers were identified to be inadequate knowledge, lack of capital and uncertainty about the return on investments for organizations".	The respondent is a bit critical to the potential ROI benefits of CE, instead only seing the environmental benefits. While not contradicting the barrier, the respondent did not seem uncertain about the ROI not being one of the main benefits of re-use
		Currently it is difficult to see circularity and re-use of materials as profitable"	Interview #1: Sustainability manager project development		Respondent is in clear agreement with the literature
		"There is value in working with reuse within an organization. However, there are uncertianties working between companies, as its costly to keep and store recycled material that someone might need in the future"	Interview #2: Project manager		The intreviewee had positive result from working with recycled material. However, found that theres big challenges to share with other companies, as the cost will outweight the gains.

		People think reused material is free. However in practice it costs more than fresh material. This is especially true if the material to be upcycled or additional work in order to be fit for construction purposes. However we can see that reusable bricks can become profitable, as it is easy to deconstruct and test material quality.	Interview #4: project manager infrastructure		Respondent describes uncertainty about the profitability, reusable material is too expensive and too risky.
		'There is more new construction than demoliton, and according to economics low supply can lead to higher cost. That in addition to the need for warehousing the materials, meaning that the higher costs will make it difficult to make reuse of materials profitable.''	Interview #5: group manager energy and climate		The respondent describes that the potential costs outweigh the potential economical gain.
		"its more expensive to work with reused or sustainably"	Interview #6 Technical energy specialist		
	High uncertainties and risks of consistent supply of recycled material	'There might be a supply and demand issue, where would potentially have too much of certain reused materials and too little of others''	Interview #1: Sustainability manager project development	(Hossain et al., 2020): ''Based on a social network analysis for analyzing the perceptions of the supply chain, Schraven et al. [9] identified the key issues for CE in the supply chains, such as a lack of incentives for actors towards circularity, lack of mutual interests among the supply chain actors, high uncertainties and risks of consistent supply.''	This might not be a perfect fit between literature barrier and barrier as described by interviewee as there are no barriers describing supply and demand issue of materials. A new barrier could potentially be ''supply and demand of reusable materials''
		'There is more new construction than demoliton, and according to economics low supply can lead to higher cost. That in addition to the need for warehousing the materials, which might need the creation of a new firm within PEAB to do, meaning further higher costs which will make it difficult to make reuse of materials profitable.''	Interview #5: group manager energy and climate		This additionally highlight the supply and demand issues, as the amount of supply is very limited as more buildings are built than being constructed while the demand on reusable materials might increase with the supply staying the same, increasing costs.
	Economic uncertainty	'Due to current world events money is tighter than normal which might affect firms ability to experiment and innovate''	Interview #1: Sustainability manager project development	(Hossain et al., 2020): ''In addition to economic uncertainty, constant supply and business risk, and lack of tools and guidelines for the design of circular products and buildings, the uncertainty related to reusing materials after their end-of-life is one of the biggest challenges of CE implementation.''	Within the current literature set, the barriers do not seem to consider the risks and uncertainties of current world events, however there are barriers that consider the risks of ''high uncertainties and risks of consistent supply of recycled material (Hossain m.fl., 2020). And supply and business risk (Hossain m.fl., 2020)''. This could possibly imply a gap in the literature.
		The current recession might possiblty be a barrier that slows CE adoption, it will be interesting to see the effects in the long run	Interview #7: Head of sustainability		This quote is simular to the previous one, however, the respondent is not as convinced about it being the main thing slowing down CE adption, but rather it being interesting to look at in the future.
	Lack of unproven business cases underpinned by viable business models	'It is hard to find circular business models that are scaleable to a whole enterprise. We have seen smaller projects that have worked well like Varvstaden.	Interview #7: Head of sustainability	(Adams et al., 2017): ''UKCG (2014) identified a key challenge of an unproven business case underpinned by viable business models such as requiring manufacturers to be responsible for their products once they reach their end of life. While this is evident in such sectors as mediumlived consumer products, it is largely absent in the built environment''	The concept of scalability is not something that is mentioned in the literature, which is especially interesting as the respondent brings up varvstaden. Varvstaden was a project that worked due to them having time, money and by chance had all the necessary conditions for reuse, something that must be impossible on a larger scale.
Barrier category and subcategory	Barrier	Quote	Data source(s)	Secondary data and literature view.	Analysis

Market: Financial	Lack of financial incentives	While counties and muncipalities push for circularity, they tend to prioritize price over sustainability, i would like to see more incentives on sustainability or circularity efforts'	Interview #1: Sustainability manager project development	"(Chen et al., 2022)": "The high costs of selective demolition are likely to hinder circular construction, which calls for financial incentives to overcome it. Without sufficient evidence, it is hard to conclude whether the circular construction is economically efficient. However, incentivizing stakeholders is an enabler. Possible solutions of financial incentives include reduced taxes (e.g., Value Added Taxes) on CE products and increased taxes on landfills, increased government funding options, reduced mortgage from investors, and reduced loans from banks (Iodice et al., 2021; Meek et al., 2021)" (Shooshtarian et al., 2022): "However, within the Australian context, incentives cover regularity requirements along with providing leadership and research and development services. This illuminates the close links between the concepts of incentives and regulations, which were ranked as the first and second barriers to the adoption of CE in the current paper. As such, the focus has shifted from financial incentives (which were found to be the barriers and enablers with the least influence) to other types of driving forces like regulatory incentives."	The interviewee describes a lack of incentives on sustainability and circular economy from a client perspective, meaning that they prioritize prize. As described by the literature, Incentivizing stakeholders are an enabler, but it does not seem like the client side stakeholders are currently financially incentivizing this enough. Meaning that in this case, literature and practiioners are in agreement. However the literature seems to focus on government side incentives rather than client incentives.
	Today, prices are low, making it uneconomical to reuse	"40 years ago we did reuse all the nails and material from the buildings, today however, we just throw and brun it. This is due to the high salerieis, its not worth it"	Interview #8, Construction manager	(Adams et al., 2017): "Additionally, many construction products at their end of life at today's prices are also low in value, making it uneconomical to reuse. Therefore, a greater understanding of the cost benefit of applying circular economy principles to each party involved is required."	In Sweden the high saleries make it inefficient for construction workers to remove each nail. As it costs more to pay saleries that material cost. In addition to the depritiated value of the material.

Science

Barrier category and subcategory	Barrier	Quote	Data source(s)	Secondary data and literature view.	Analysis
Knowledge: Lack of information	Lack of knowledge	'While i see circularity as a necessity, we are all newcomers to it, it is a bit of unexplored ground for us	Interview #1: Sustainability manager project development	(Shooshtarian et al., 2022); "awareness and knowledge to take CE to the stage of adoption and implementation were deemed to be problems. Figures stated by the participants showed that 40.6% of participants'organizations applied CE principles in their projects to a limited extent."	Interviewee and literature seem to be in agreement. The awareness of circular economy seems high, especially as it is seen a necessity. However actually implementing it into projects seem to be unexplored and practitioners are unaware on how to proceed with it.
		'As far as i am aware, PEAB is working with circularity alot, however it comes in waves, i do not have much personal experience however."	Interview #3 Site manager		While respondent 2's quote fit in the "Lack of knowledge barrier", respondent 2 places focus on their own lack of experience.
		'Circular economy is a new concept for the industry, there is some slight pushback., but less than i expected"	Interview #7: Head of sustainability		The respondent describes that it is a new concept and must be explored and diffused further within the sector
		"there is a lot of difficulties working with buildings if your aiming to deconstruct it. For example you could theoreticaly skip joint casting, to enable deconstruction. But then there will be noise problems, where you need to add steel welding to combat that problem, so many solutions add different problems. Making it more difficult than you think."	Interview #8, Construction manager		From the interviewee there was a lot of intresting perspective related to technical difficulties, with knowledge related to new methods being one of those.
		There can be a lack of experience when working with sustaianbility and circularity	Interview #6 Technical energy specialist		When working with sustainability theres can be a lack of experience. which can affect cost or time

Barrier category and subcategory	Barrier	Quote	Data source(s)	Secondary data and literature view.	Analysis
Knowledge: Information diffusion	N/A	'Currently, the construction sector only considers circularity as a method for sustainability, rather than the wider perspective of circular economy. There is a journey the construction sector has to do there". "There is a difference of understanding and focus on different things in discussions regarding CE currently, such as Circular flows VS carbon emissions." "One of the challenges for circularity in a project development role is that it is heavily tied to sustainability questions, however you can still be climate neutral but still be bad for the planet due to the amount of resource usage"	Interview #7: Head of sustainability		Quote describes that the construction sector has a narrow view of the CE concept. Which currently does not have a clear parallel in the literature. However it could be tied to several other barriers, such as lack of knowledge, however it seems to fit the best into the information diffusion subcategory
		I have previously only focused on the operational phase, reducing energy use, but now we have come so far down that the question is, should we really have such thick walls or not?When you haven't looked at energy consumption and such to build the house, maybe you shouldn't have so much insulation. Insulation may have a worse climate impact than what you save. "were currently only focusing on the parameter climate, maybe we should look into other aswell"	Interview #6 Technical energy specialist		

Policy

Barrier category and subcategory	Barrier	Quote	Data source(s)	Secondary data and literature view.	Analysis
Laws and regulations: Regulations	Lack of environmental regulations and laws which is driving the rest of the barriers to the circular economy	"Some regions in sweden has different requriments, some need to work with eco-concrete or recycled material, however its not applied everywhere"	Interview #2: Project manager	(Bilal et al,.2020): "Its the lack of environmental regulations and laws which is driving the rest of the barriers to the circular economy"	The inconsistance in laws and regulations is dependant on region, which is a major barrier to the adoption of circular economy.
	N/A	'Currently there are too many upcoming environmental regulations which causes too many quick and inefficient changes which create more practical challenges which simply prevent us from using leftover materials from a next door building project"	Interview #3 Site manager		Within all the examined literature, there are no applicable barriers that could be tied to the quote. This might imply that current CE literature does not consider too many new environmental regulations as a barrier

					In fact, it actively contradicts the "Lack of environmental regulations and laws is driving the rest of the barriers to the circular economy" barrier
		"There are many laws and regulation related to construction, there are demand on stairs, doors, and so on which needs to be fullfilled, which hinders the reuse of material as they dont fullfill todays standards. Making in impossible to reuse.	Interview #4: project manager infrastructure		
Barrier category and subcategory	Barrier	Quote	Data source(s)	Secondary data and literature view.	Analysis
Laws and regulations: Ownership	Lack of legal warranties on recycled or reused materials	'Guarantees might be an concern the entire industry might need to solve when working with reuse"	Interview #1: Sustainability manager project development	(Chen et al., 2022): "The blockchain technological platforms provide opportunities for "usage-based" insurances, which would ease the insurance constraints and increase the legal warranties of recycled and reused materials (Kouhizadeh et al., 2019). Traditional ownership models are hard to change, and particularly the legal meanings of the ownership may differ in different law settings."	There are concerns presented by the interviewee that are echoed by the literature. Current ownership models might serve as an barrier when considering re-use, as it might affect existing warranties.
		"No one want to work with recycled material due to there are no warranties, due to the lack of information/papers on the material, leaving actors unable to give warranties to the customer"	Interview #4: project manager infrastructure		Warranties, and risk is key issues related to resuing material, however, Adams (2017) argues the need to establishment of the ownership of material, as its an important part to facilitate a CE, Theres a need to recycle material and the intreviewee agree that this is a matter of time before companies need to reorganize the waste management.
		'Large construction enterprises are hesistant with working with reusable materials due to lack of documentation, if something fails, who carries responsibilities?"	Interview #5: group manager energy and climate		Respondent presents simular argumentation as previous ones, even if not specifically mentioning guarantees, just documentation. Is in clear agreement with the literature

Industry

Barrier category and subcategory	Barrier	Quote	Data source(s)	Secondary data and literature view.	Analysis
Infrastructure/Supply chain: Integration	lack of integration of sustainable waste management and potential reuse	"There is a place where we store material storage of dissasembled materials. However theres a lack of knowledge how to access it"	Interview #2: Project manager	(Hossain et al., 2020): "One of the key challenges of CE adoption is the Design stage is the lack of integration of sustainable waste management and potential reuse,"	The Interviewee describes that there is a possibility to reuse material however theres a lack of integrated management of those resources. This highlights the barriers Hossain spoke about. The classification is between infrastructure and knowledge is due to there being material storage, but its not integrated and used during early stages of projects. Which was partially related a lack of knowledge on how to access it or integrated management to facilitate the usage of the material.

					Cimen states that there need to be an international resouce bank with a standardized information system to Support a transition towards a CE
	Inadequate communication with clients, designers and subcontractors	"It can be difficult to get informations related to the material in itself, when wanting to do LCA calculations"	Interview #6 Technical energy specialist	(Hossain et al., 2020): "in order to promote CE in the construction industry, there must be an in-depth teamwork and consultation between project teams from the conceptual stage throughout to the handing over of these projects. These consultations could be implemented through industrial workshops and seminars and collaborating businesses and agencies to stimulate demand for CE and promote the CE agenda in general Inadequate communication with clients, designers and subcontractors; lack of leadership skills; and low acceptance of idea are also important barriers [77,92]. "	As seen from the interviewee there can be challenges regaring information collection, due to sub-contractors and suppliers not working with it themself. Or a lack of communcation between the actors.
Barrier category and subcategory	Barrier	Quote	Data source(s)	Secondary data and literature view.	Analysis
Infrastructure/Supply chain: Incentives	Lack of incentives for actors in a supply chain to adopt CE	"Currently theres a lack of actors working with CE"	Interview #4: project manager infrastructure	(Hossain et al., 2020): " key issues which is the lack of incetives for actors towardsa circularity, which results in high uncertianties and risks of consistant supply, and clashes of perception in all levels of the supply chain"	From the interviewee there was a lack of actors when wanting to work with circular constrction, explaining various barriers resulting from the experiences. This is highly related to other barriers such as economic, time, and regulatory. Both the literature and the interviewee presents a consistency here
Barrier category and subcategory	Barrier	Quote	Data source(s)	Secondary data and literature view.	Analysis
Infrastructure/Supply chain: Risks and uncertainty	Supply and business risk	Projectdevelopment and design need to be done in early stages, with up to 2 years before condstruction, where you need to decide on material early, and with reused material there is a difficulty related to obtaining correct material at the right time, if you dont want to house the material up to 2 years"	Interview #4: project manager infrastructure	(Hossain et al., 2020). "In addition to economic uncertainty, constant supply and business risk, and lack of tools and guidelines for the design of circular products and buildings, the uncertainty related to reusing materials after their end-of-life is one of the biggest challenges of CE implementation"	Currently there is no infrastructure for project or construction managers to use reuseable material, as theres no infrastructure set up to support the needs a construction project has. Hossain say that to construction using a circular construction due consideration of environmenal and economic sustainablity is very site specific. Which depends on nemerous factors, including the type of building and its desing, materials type, building elements, transport distances, local economic and political context.
		"To work with circularity theres a need for someone to stockup on material and a market to sell the material to. Currently this does not exist, making it difficult to work with reused material"	Interview #8, Construction manager		

Table 17: Data structure