Business Strategical Proposals for Implementing Reused Windows in Industrial Construction

An Analysis from a Stakeholder Perspective

Master's thesis in Design and Construction Project Management

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Abstract

It is known that the construction sector accounts for a sizeable share of the total waste generated annually. With various climate targets pushing towards sustainable development, this sector needs to become more circular. Reusing materials and products is seen as having a great potential in reducing the amount of waste and negative environmental impacts the sector has today, although this is often easier said than done. Windows are considered to be one of the more complex components to reuse. In addition, the conditions for implementing reused windows differ depending on the type of construction process and building.

The aim of this master thesis was to identify the conditions of using reused windows into newly produced, prefabricated multi-family dwellings, in order to present business strategy proposals for companies within this area of business. A literature review was conducted to understand what barriers currently exist and to identify main stakeholders that are to be involved in the development. The theoretical framework was used as a basis for the interview study which consisted of 10 interviews with stakeholders from different parts of the construction value chain. The interviews were categorised to answer the question of which stakeholder should drive the change, what business changes are required in the studied company, conditions on how windows can be reused and how it can be applied in prefabrication.

The results showed that there is no single actor taking sole responsibility, as the whole sector must embrace this reform. However, the actor that will have a major influence towards the implementation of reused windows in prefabricated production are the client. The results also showed that large parts of the buildings that will be dismantled in the near future have windows installed that will not meet the current requirements. Further, the results also showed evidence that the main obstacles are not related to prefabrication but occur much earlier in the value chain. However, obstacles that needs to be addressed concerning prefabrication is increased time- and cost aspects regarding uncertainties of attachments and design changes, as a result of the standardized and otherwise effective lead times.

The conclusion drawn presents business strategy proposals for improvement potentials to facilitate the reform towards using reused windows in prefabricated production. The proposals concern internal business initiatives, prefabrication, and sectoral collaboration. Finally, suggestions for further research on the topic are discussed.

Keywords: reuse, windows, circular businesses, prefabrication, off-site construction, industrial production, stakeholders

Preface

First, we would like to thank our supervisor and examiner from Chalmers, Martin, who has been very helpful during the spring and made this work possible. When the work has felt overwhelming, you have provided positive feedback, which has been appreciated!

Many thanks to Derome for the cooperation, and in particular to Anders who has been our supervisor at the company. It has been appreciated that you have contributed with interesting views and being helpful in providing contacts for interviews.

Thanks also to all respondents who have agreed to interviews and shown great interest in this study.

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Cassandra Boman & Nike Kruners, Gothenburg, June 2022

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Nomenclature

Agenda 2030	UN Sustainable Development Goals. An action plan containing goals and targets for making the society sustainable, including the three dimensions of sustainable development: social, economic, and environmental.
BIM	*Building Information Modelling* 3D modelling in the construction process making projects more visualised. Mainly used to gather information about buildings and to assist in decision making
The Building Board	It is often called the Swedish Planning and Building Act, which sets requirements for how municipalities should deal with certain matters regarding construction sites.
Circular economy	The life cycle of a product/material is seen as circular, i.e., when it reaches its end-of-life it should be recycled and/or reused and not go to landfill.
CO_2	*Carbon dioxide* An important greenhouse gas with biological functions for biodiversity.
DfD	*Design for Disassembly* A concept in which buildings are designed with the intention of meeting future changes by facilitating dismantling and streamlining the recycling and/or reuse of entire systems, components, and materials at the end of the building's lifespan.
GHG	*Greenhouse gasses* Gases, mainly carbon dioxide, methane, and water vapor, which contribute to increased greenhouse effects through their properties of absorbing infrared radiation.
Linear economy	Unlike circular economy, linear follows a straightforward model, where the life cycle of a product and/or material can be described as; take, make, use, and dispose
National Board of Housing, Building and Planning	State authority under the Ministry of Finance. The Authority monitors developments in the housing, construction, and planning sectors.
Recycle	Giving new life to products and/or materials instead of throwing it away.
Reuse	The definition of reuse according to 15^{th} Ch. 2 § of the Environmental Code is "the reuse of a product or component that is

not waste to fulfil the same function for which it was originally intended."

Stakeholder	Anybody that can affect or is affected by a strategy, project, organization etc. Can be an individual or a group.
Waste hierarchy	A way of prioritizing waste management options. Prevention has the highest priority followed by reuse, recycle, recover, and last disposal. (European Commission, n.d.

1 Introduction

This chapter provides background information that gives an overview of the current climate problems, possible initiatives for sustainable development such as circularity and reuse of components, as well as a presentation of the investigated problem of implementing reused windows to organizations within the business of prefabrication. Furthermore, the aims and problem formulation conducted for this master thesis as well as the report structure are also included in this chapter.

1.1 Background

Over the last century, developments in technology, health, transport, and housing have made the world a better place to live for large parts of the rapidly growing world population. Although society has improved in numerous ways, there are still challenges to overcome. At the national level, there is a housing shortage in Sweden, as a result of the rapidly increasing population and urbanisation. In Sweden the building need estimation for the period 2021-2030 showed that 60 000 dwellings must be built annually to meet the current housing shortage (Boverket, 2021). It will continue to require substantial work from the construction industry to provide this need. At the same time, this sector, together with society at large, faces major challenges in developing sustainable processes to achieve, among others, the global sustainable development goals of Agenda 2030. The truth is that the construction industry is directly linked to extensive extraction of natural resources and finite materials. This results in major natural consequences in terms of increased pressure on already exceeded planetary boundaries, as well as generating high levels of greenhouse gases (GHG) and waste (Fossilfritt Sverige, 2018; Göteborgs Stad, 2020).

Today, there are various standards, directives, and codes of practice in the building and construction sector to reduce its carbon footprint. In addition, there are indications that stricter rules on the use of materials will be needed in the future to achieve the net emissions targets and the global goals of Agenda 2030 (Boverket, 2021). Reducing the environmental impact of the construction sector can be done, inter alia, with the aim of increasing circularity. Circular material flows and resource management are important and essentially involve making materials and products more efficient by extending their life cycle through reuse and/or recycling. There is evidence of great potential for development and opportunities for the construction industry to adapt circularity to the now largely linear sector (Göteborgs Stad, 2020). Furthermore, there exist various directives for waste management, including the waste hierarchy. Waste management should follow five steps, with reuse being the second step after minimisation. Despite this, only about 10 tonnes of a total of 9 million tonnes of waste is currently reused annually (Andersson, Gerhardsson, Kronberg, Lindholm, Shadram & Wennesjö, 2020).

What can be seen is that reuse is likely to play a greater role in the construction industry, as a way to keep the carbon footprint down. However, the potential for reuse varies depending on the type of material and product along with its previous use (RISE, n.d.). One product that is sought after to be reused on a larger scale is windows. Today, it is common to reuse components other than windows, and if windows are reused, it is often in the form of one-off purchases by private individuals renovating or for buildings where the thermal requirements are lower, such as complementary buildings. Windows are demonstrably a complicated product to reuse because there is a number of different building requirements that have to be met, as well as the product having a large impact on the overall energy consumption of a building (Andersson, Gerhardsson, Lindholm, Moberg & Wennesjö, 2021b).

This thesis has partly been carried out as a study of, and a collaboration with, a company that constructs prefabricated multi-family dwellings. The investigated company has expressed a curiosity and willingness in being able to reuse windows in their prefabricated house modules, which the company in the future believe can become one of the solutions to bring down the carbon footprint. Industrial construction is a complicated, streamlined, and standardized construction process, and is particularly sensitive to change (Eltoukhy, Hussein, Karam, Shaban & Zayed, 2021; Hewage & Kamali, 2016). Additionally, how the implementation of reused windows would change the process is something that has not been widely studied before.

1.2 Problem Formulation

As mentioned above, reuse can be one of the solutions to reduce the environmental impact of the construction sector while meeting the likely stringent future requirements of material use. Furthermore, actors within the construction sector express a desire to increase the use of reused materials although the conditions do not match the will to do so (Andersson J. , et al., 2020). The implementation of reuse is challenging in such already highly developed sector that has a major impact on society and its people. In addition, it will be a test to bring such an energy-demanding, short-lived, and advanced component as windows into the standardized and change-sensitive construction process of prefabrication. For this to be possible, some organizational restructuring is likely to be required for companies in this type of business. This study will therefore explore the possibilities of reusing windows in prefabrication through stakeholder analysis and finally provide business strategy proposals to facilitate implementation. These proposals will be based on discoveries from a theoretical framework together with an interview study.

1.3 Aim

The aim of this master thesis is to investigate which areas of development needs to be addressed to facilitate the reuse of windows based on a stakeholder analysis and an interview study. The current usage of reused window components will be examined and how this usage can be increased and applied within the standardized industrial construction, henceforth referred to as prefabrication. The knowledge will then be used to present business strategical proposals for construction companies working with prefabricated multi-family housing so that the process of implementing reused windows can possibly be enabled. To achieve the aim, the study is based on the following research questions, where also the opportunities and difficulties of reusing window components are investigated:

1. What stakeholders are needed to successfully implement reuse of window components?

2. What business strategy changes are required for these types of construction companies to reuse window components in their industrial construction projects?

1.4 Limitations

This thesis focuses only on reuse and has not taken into account other steps in the so-called waste hierarchy nor opportunities and challenges related to other circular transitions of the construction industry. The same applies to different types of reuse. In this thesis, the term *reuse* will correspond to reuse of whole components, where for instance *adaptive reus*e (the process of reusing an existing building for a different purpose than it was originally built for) has not been included in the study. The analysis and conclusion of the thesis can only be applied to the reuse of window components. However, previous studies on reusing older windows into new constructions are limited, hence parts of the literature study will be based on reuse of components in general. This to gain information about comprehensive hinders and possibilities of reuse.

Moreover, the focus will largely be on new developments, more specifically prefabricated multi-family housing, and thus will not include the application of reused window components to construction projects such as renovation or refurbishment.

The interview study and result will be limited to Sweden. However, research from other countries regarding the subject that provides general knowledge have been used during the literature study. How reuse of the chosen component can be applied in the business of Derome is the main focus, even though some conclusions and analyses can further be applied to, and used by, similar businesses in the construction sector.

1.5 Report structure

This thesis is divided into five main chapters, starting with an introduction to the studied subject and ends with a conclusion to the research questions and suggestions for further research. Brief descriptions of all chapters are presented below:

Chapter 1 Introduction: This section consists of a background presenting the problematics of the chosen topic, research question along with presenting the aim of the thesis together with the limitations applied in its execution.

Chapter 2 Theoretical Framework: This chapter deals with existing facts and theories on the subject studied, which will provide the reader with general knowledge for further understanding in the course of the report.

Chapter 3 Methodology: This part of the report presents the selected methods and approaches used to achieve the report's objectives. It also presents a description of the company studied.

Chapter 4 Interview study: This section presents the results of the interview study, i.e., a comparison and integration of the different interviewees' answers.

Chapter 5 Discussion and Conclusion: In this chapter, the findings from the theoretical framework and interview study have been further analysed, discussed, and compared which developed a conclusion to answer the purpose of this master thesis. Discussion of methodological choices and suggestions for further research are also included in this chapter.

2 Theoretical Framework

This chapter presents the theoretical framework that introduces concepts and definitions of theories of importance to this study. It provides information on the barriers and opportunities that exist for reuse of components in general within construction along with specifics of reused windows. Furthermore, the theoretical framework presents how business models need to apply circular practices, and the identification of the primary stakeholders in the construction sector that may have an impact on the implementation of reuse in prefabrication. The stakeholder identification was later applied to the interview study presented in Chapter 3.3.

2.1 Windows

Windows represents 10-20% of the wall area and are therefore an important part of the climate screen, both architecturally and in terms of construction technology. There are several functions and requirements that windows must fulfil regarding fire, sound classes, air- and rain tightness etc. (Salazar & Sowlati, 2008; Frighi, 2022; Khan, Moeseke & Souviron, 2019; Laven & Strandberg, 2019). Furthermore, approximately one third of the heat supposed to warm the building is released through windows and they can thereby be considered as the weakest link in the climate screen, accounting for 60% of the building's energy consumption (Frighi, 2022; Kutnar & Sinha, 2012; Khan et al, 2019).

The heat transfer coefficient, U-value [W/m^2°C], measures how much heat that is let through a material, the lower U-value a window possesses the better heat resistance it has (SP Fönster, 2019; TMF, 2010). Although heating regulation has been strengthened in the EU, work regarding improving the energy efficiency of buildings continues, where the design and performance of windows play a major role (Khan et al., 2019).

The National Board of Housing, Building and Planning has developed rules and regulations regarding windows with daylight as a starting point. Approximately ten percent of the floor area of a room should cover the walls with windows to meet requirements regarding light incidence. The European Standard called SS-EN 14351-1 can be helpful when choosing windows since it gives an overview of different requirement levels and important window properties (Laven & Strandberg, 2019). Windows must be sealed against both air and rain while maintaining a long service life (Khan et al., 2019; TMF, 2010).

Windows can be divided into different categories, openable or non-openable as well as by the type of glass that is being used: 2-glazed, 3-glazed, or coupled 2+1 glass are some of the different options (SP fönster, n.d). As the designations explain, a triple-glazed window has three glass panes joined together and a double-glazed window has two glass panes. When it comes to the coupled 2+1 glasses, it has an outer and an inner window frame where the inner frame has a double-glazed window and the outer frame a single glass. The double- and triple-glazed windows are good alternatives when it comes to both heat and sound insulation as well as maintaining a lower energy consumption (SP fönster, n.d). When using windows with multiple glazing it can usually consist of a gas between the different layers of glass, instead of air, to increase its thermal insulation capacity and noise transmission (Laven & Strandberg, 2019; Muneer & Weir, 1998; Salazar & Sowlati, 2008). The gases that are typically used for this is either argon, krypton, or xenon, which all are gases that already exist in the atmosphere. However, the process of filling the windows with gas must be carefully controlled to ensure that the amount and pressure of gas is correct and not too wasteful (Muneer & Weir, 1998).

The arch is the part of the window that is attached to the wall whereas the frame is the part that surrounds the glass (SP fönster, n.d). As for the material for the frames, timber, aluminium, PVC, or a combination of those are the most commonly used (Laven & Strandberg, 2019; Salazar & Sowlati, 2008). According to Khan et al. (2019) a window has an estimated lifetime between 30 to 40 years. However, the lifetime depends on many factors such as the frame material and maintenance. Henceforth, aluminium frames have an estimated lifetime of approximately 44 years, PVC 24 years and timber 40 years (Khan et al., 2019; Davidsson et al., 2002).

Of the three most used frame materials, timber is the most traditionally used material even though all three material options have different advantages and disadvantages. In the case of timber, many tons of threes are being cut down every year which releases approximately 2 billion tons of CO_2. However, timber is still considered to be a renewable material (Muneer & Weir, 1998; Muhammed et.al., 2002). Compared to other materials, such as aluminium and PVC, timber has low embodied energy and low conductivity (Davidsson et al, 2002). In addition, timber requires additional maintenance and is therefore one of the most demanding materials, partly due to weather conditions where it tends to swell and crack at higher temperatures and higher humidity (Salazar & Sowlati, 2008; Frighi, 2022; Davidsson et.al., 2002; Khan et al., 2019).

Window frames and arches made of aluminium can be both beneficial and harmful from an environmental perspective (Davidsson et al., 2002). The strength of aluminium makes it resistant to different weather conditions, but the production of aluminium is extremely energy consuming as well as contributes to high emissions of CO_2 and dust (Davidsson et.al., 2002; Khan et al., 2019). However, according to Khan et al. (2019) the environmental impact can be lowered by using recycled aluminium and Davidsson et al., (2002) emphasizes that there is no limit for how many times aluminium can be recycled and/or reused without affecting the materials quality. A window frame with a material combination of wood and aluminium would be easy to maintain, having the low environmental impact from wood and the strength from the aluminium. This solution, which to a degree is being used today have potentially longer service life in comparison to only using one of the materials (Khan et al., 2019).

Polyvinyl chloride also known as PVC, is a synthetic material. A window frame made with PVC must include reinforcements from metal and PVC must be protected against high temperatures as the material is sensitive to it (Davidsson et al., 2002). PVC is hard to recycle due to it containing hazardous substances (Davidsson et al., 2002; Khan et al., 2019).

2.1.1 Environmental impact of windows

Life cycle assessment, LCA, is a popular tool in climate change mitigation. Within the construction industry, LCA can be used to investigate what processes and materials that have the biggest environmental impact to know where the change must happen (Boverket, 2019). As LCA examines the entire life cycle of a product, including material extraction, energy production, manufacturing, transport, and waste management, it must be carried out in the early design stages (Muneer & Weir, 1998; Boverket, 2019). Figure 1 below presents a generalized LCA process from cradle (raw material extraction) to grave (end-of-life). The figure also shows the stages of recycling and reuse.

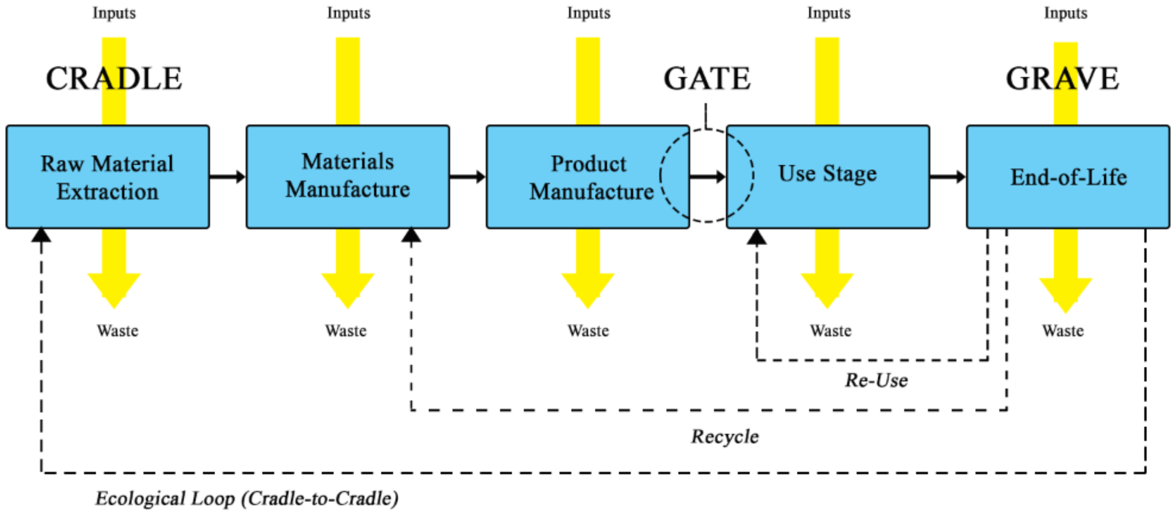

Figure 1. Generalized description of processes analyzed in an LCA. (Commons Wikimedia, 2022)

It is challenging to provide a developed and in-depth LCA for windows because the analysis is highly dependent on the materials used and different materials must undergo different types of processes in the manufacturing (Salazar & Sowlati, 2008). Once installed, the windows emit only a small amount of emissions, but at the same time affect the energy consumption of buildings during operation (Khan et al., 2019; Salazar & Sowlati, 2008). For construction in general, it is the decisions taken at an early stage that are important and can have an impact on the environment. However, the actors, e.g., architects, involved in the early phases often do not plan for the dismantling of buildings and/or how to reuse and recycle the different parts of the building, which affects the LCA analysis. (Khan et al., 2019; Avellaneda & Vefago, 2013).

Timber is the material that have the smallest impact on the environment due to its low embodied energy, as well as the best thermal characteristics (Khan et al., 2019; Salazar & Sowlati, 2008). As previously mentioned, timber is a material that requires maintenance during its lifetime and during the windows lifetime the heat loss through the frame will increase (Khan et al., 2019; Salazar & Sowlati, 2008; Davidsson et al., 2002). At the end of the timber frames´ lifetime it will most likely be sent to landfill since the surface treatment that the materials have been maintained with during its lifetime makes it more complicated to reuse and recycle (Davidsson et al., 2002; Khan et al., 2019).

Aluminium has a recycling rate of approximately 40% in Europe, even though Khan et al. (2019) emphasizes that this rate can be increased to up to 95%. When producing PVC, it has a greater impact on the environment in comparison to timber where PVC requires approximately 3 times more coal and oil which generates seven times more CO_2 than the extraction of raw material in timber production (Khan et al., 2019). To produce PVC is more complex than the production of both aluminium and timber and compared to these materials it also has relative low recycling and reuse rate. The reason for this is that the process of reusing PVC is rather cost consuming, sometimes even more expensive than using raw materials (Khan et al., 2019; Salazar & Sowlati, 2008). Generally, in the construction industry there are a number of stakeholders pushing for the recycling and reuse of these three types of materials. However, factors such as lack of technology, multiple processes, demolition, and transports are actions that makes the reuse and recycling a challenge as they tend to damage the materials (Salazar & Sowlati, 2008).

2.2 Reused Components

The construction industry is responsible for 25-30% of all waste generated each year (Kärki & Sormunen, 2019; Gorgolewski, 2008; Wennesjö et.al., 2021). As a measure to reduce the environmental impact, new legislation on reuse and recycling has been necessary. The definition of reuse of components can be translated as when a building has been dismantled and/or demolished, the materials and various components are given the opportunity to continue their life in new buildings and/or for other purposes (Wennesjö et.al., 2021). In 2020 changes were made in the Planning and Building Act, 2010:900, with the intention of minimizing waste by making them into circular resources. The law required that the client must report the amount of waste that is produced from different projects as well as how the waste will be handled. By using this control plan, the National Board of Housing, Building and Planning and the Swedish Environmental Institute believe that it would generate an estimation of how many cases there are where reused products will be requested (Franker, Lunneblad & Wilson, 2021).

There are many reasons for increasing reused and recycled components within the construction industry where the reduced carbon footprint is one of the major motivations (Kärki & Sormunen, 2019; Gorgolewski, 2008). Furthermore, Gorgolewski (2008) presents data from a study where the energy benefits of improved material management where investigated. By reusing materials such as steel and glass, GHG emissions can be reduced by 60% in comparison to recycling these materials (Gorgolewski, 2008). Even though the environmental benefits from reuse are straightforward there is a certain gap between attitudes and approaches within the construction sector regarding reuse (Andersson et al., 2020). Overall, stakeholders' attitudes towards reuse are positive, mainly since environmental questions are getting a greater deal of attention today. Stakeholders being at the forefront of reuse and recycling provides business opportunities to market themselves as pioneers in the circular economy. However, even though the attitudes are positive, there is still a low level of reuse within the construction industry and there are a lot of room for improvements (Andersson et al., 2020).

According to Andersson et al. (2020) the process of deconstructing a building must start with the preparation which includes four different steps, see Figure 2. The first step of the preparation is a material inventory which also corresponds to the model discussed by Franker et al. (2021). Both Andersson et al. (2020) and Franker et al. (2021) emphasizes that the material inventory must be implemented frequently as a first step since it is the basis for the decision making later on. The inventory investigates what materials that can be reused in an existing building and thereby sets the standard for the potential and quality of the materials, which is necessary information to enable planning and designing for a new building (Franker et al, 2021; Andersson et al., 2020).

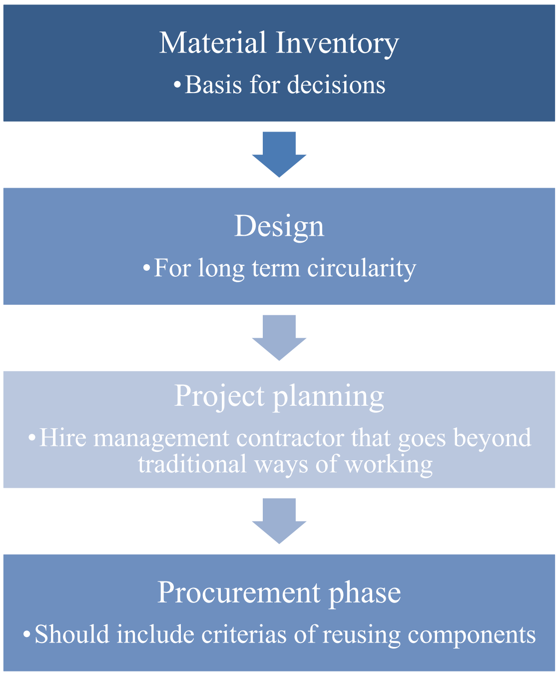

Figure 2. Preparation process of deconstructing a building

After the material inventory has been conducted, the buildings can be designed with the reusable components in mind. The inventory has given the architects the knowledge of which materials and/or components that can be reused, thereby avoiding the need to redesign the building at a later stage, which tends to happen if the inventory is not completed properly (Franker et al., 2021). During the design phase the building should be designed for long-term circularity. From a circular perspective, the building should, if possible, be designed to accommodate different functional areas. Circularity also includes a continuous focus on designing components so that they can be reused. If that is not possible, the components should be recycled at the end of their life and thereby prolong their service life for as long as possible (Andersson et al., 2020; Sassi, 2008). According to Gorgolewski (2008), the easiest way to reuse components in a new construction is to use them in a similar way as their original function in the previous building by using the same layout and dimensions if possible.

The third stage of preparation is project planning, although this should have been considered during the materials inventory and design phase as well (Andersson et al., 2020). During the project planning a management contractor can help with the implementation of reused components. However, this management contractor should not only be used during the project planning phase, but they must be hired earlier during the design phase (Gorgolewski, 2008). When implementing reused components in a project, there are risks that tend to arise in terms of time and availability, since it requires time to search for materials that can be reused (Gorgolewski, 2008; Andersson et al., 2020). A management contractor can work specifically with these issues and according to Gorgolewski (2008), the management contractor in comparison to a traditional contractor are more willing to adapt to the necessary changes that will go beyond the more traditional way of working with projects.

Fourthly, the procurement phase, which is the last step of the preparation phase before entering the phase of execution and during the procurement there should be a criterion of reusing components (Franker et al, 2021; Andersson et al., 2020). However, Andersson (2020) explains that in order to introduce reuse in procurement, barriers need to be removed and procurement needs to become more accepting. This may include more financial incentives regarding reusing components as well as planning for the time it will take and having specific requirements that components must be reused (Andersson et al., 2020). In addition, as mentioned above, a management contractor is helpful in the planning of the project, but also in the procurement phase, as they have to some extent more experienced in reuse (Gorgolewski, 2008).

Once the preparations are done, the next step is to execute the project. The first step is dismantling followed by new construction if the project is to be carried out in the same place, so to speak. At this phase it is necessary to create a market for reused components so that they can be used for the new construction. Furthermore, deconstructed materials and components that are of high quality should be available at the market for other projects if they are not used (Andersson et al., 2020).

Once the building has been dismantled and the different components have been sorted into reusable and recyclable, it should be sent to material handling facilities before re-entering the market. If not used in a new project, the material can be sold and later reused somewhere else (Kärki & Sormunen, 2019). However, in order to be more successful in dismantling buildings that allow for the collection of the reusable components, the buildings should be designed for disassembly, DfD (Sassi, 2008; Gorgolewski, 2008; Franker et al., 2021). A building designed for disassembly must meet certain requirements so that the reusable components can be deconstructed without being destroyed. Therefore, when designing buildings, there should be information on the different components and how these should be deconstructed in the correct way. Cost implications are a potential factor that could hinder buildings from being designed for disassembly (Gorgolewski, 2008; Sassi, 2008). Increased costs could occur as a result of the extended amount of time necessary to deconstruct a building even though the process of reusing components might as well become profitable in the long run. This due to decreased landfill taxes and that a smaller number of new materials must be bought (Gorgolewski, 2008; Sassi, 2008; Franker et al., 2021).

As mentioned, the buildings should be designed for disassembly which means that the architects and designers have a great responsibility (Franker et al., 2021; Gorgolewski, 2008; Sassi, 2008). Gorgolewski's (2008) study presents architects' and designers' experiences of reuse, e.g., whereas when reused components are integrated into the design, a new and increased complexity is created in the project. One of the reasons for the increased complexity is that demand does not match supply, due to the fact that the necessary components may not be available at the right time, in the right quantity or in the right size. This makes it more difficult to coordinate the project compared to traditional design processes where mainly standardised models and components that meet the architects' preferences are used (Franker et al., 2021; Gorgolewski, 2008; Sassi, 2008). The reused components are often identified during the demolition of buildings, and therefore may not be available during the design phase, implying that the building may have to be redesigned later when the components are available (Franker et al., 2021; Gorgolewski, 2008).

Chapter 2.2.1 below further explains the barriers that may prevent the reuse of components. However, as discussed above, there is a problem that the current building stock has not been designed in a way that allows it to be deconstructed (Sassi, 2008). One of the reasons for this is lack of technology, partly because technologies were not as advanced at the time when today's building stock was constructed and partly because in some cases the technology is still not fully developed to its true potential. Making greater use of, for instance, BIM can not only improve the design phase of buildings but also help in the processes of deconstructing and sorting out the reusable and recyclable materials (Kärki & Sormunen, 2019; Sassi, 2008).

2.2.1 Barriers

Table 1 illustrates the barriers of material and component reuse in the construction sector. The presented barriers can be considered key barriers, as they are more important to solve but also interlinked. In other words, if the construction industry can come to an understanding of how to overcome one of these barriers, it will have a simultaneous impact on the others (Andersson et al., 2020).

Table 1. Barriers of implementing reused components in a project

Barriers	**Description**	**References**
Attitudes	An unwillingness to try due to e.g., lack of knowledge and experience	(Andersson, Gerhardsson, Holm & Stenmarck, 2018; Andersson et al., 2020; Andersson et al., 2021b)
Logistics	Lack of storage facilities as well as not enough knowledge regarding the logistics of deconstruction	(Andersson et al, 2018; Nußholz, Nygaard, Whalen & Plepys, 2020)
Lack of actors	The business models are not fully developed to work with reused components	(Andersson et al, 2018; Andersson et al., 2020)
Economic	Reuse is time consuming due to lack of knowledge which makes the process more costly	(Andersson et al., 2018; Sormunen & Kärki, 2019; Andersson et al., 2020; Andersson et al., 2021b; Almasi, Hwargård & Miliute-Plepiene, 2020).
Quality assurance	Inexperience and lack of knowledge makes the quality assurance difficult	(Sormunen & Kärki, 2019; Andersson et al., 2020)
Lack of knowledge	Lack of knowledge on how components can be reused to its full potential	(Sormunen & Kärki, 2019; Andersson et al., 2020)
Availability	The immature market makes it difficult to find components	(Andersson et al., 2020; Sormunen & Kärki, 2019; Almasi et al., 2020).

Knowledge is one of the key barriers, as presented above. An increased knowledge of how to reuse components will also minimise the impact of the other barriers. According to the literature, there is a general lack of experience in the construction industry regarding reuse of components as a substitute to new products. In addition, there is insufficient knowledge on how to deconstruct and manage materials afterwards in a way that allows reuse (Andersson et al., 2020; Sormunen & Kärki, 2019). Andersson et al. (2020) and Andersson et al. (2018) also point out that there are not enough actors in the industry with the experience needed for a wider implementation. The, current, limited extent of projects that have used reused components cannot prove the full potential, provide enough good examples, and increase the dissemination of experience and knowledge. Lack of experience also leads to ignorance, which in itself has a negative impact on attitudes towards reuse (Andersson et al., 2020; Sormunen & Kärki, 2019; Andersson et al., 2021b). However, the attitude towards reuse is not only in the hands of construction organisations, but also depends on the attitude of the actors involved. If the parties involved have a positive attitude towards material reuse, they are more likely to be able to implement and succeed in accordance with the objectives (Andersson et al., 2021b).

Today there is a lack of availability of materials to reuse, with ignorance being one of the reasons for the immature market (Sormunen & Kärki, 2019; Andersson et al., 2020; Almasi et al., 2020). At the moment, there is a limited supply of reused components that has the quality needed, especially when a project requires a large number of similar components. Andersson et al., (2020) explains further that the immature market for reusable components is a consequence of the underdeveloped value chain of stakeholders with not enough knowledge, storage facilities, quality assurances and demand. Furthermore, if the market for reused components were developed it would increase the processes that are considered as cost and time consuming as well as the quality-assurance systems would automatically be improved (Andersson et al., 2020). Nevertheless, the study conducted by Andersson et al. (2021b) showed a positive trend where the quantity of supplies and number of actors have increased between 2019 and 2021. This could arguably show a positive effect on the knowledge deficiency and the market (Andersson et al., 2021b).

Within the construction industry there is always concerns regarding costs where the short-term perspective plays a big role. One of the major reasons that reusing components is seen as an economic barrier is due to the time it takes to do the inventory. This can be interlinked to buildings not being designed for disassembly as well as knowledge barriers on how to deconstruct the buildings so that these components are reusable afterwards (Almasi et al., 2020; Kärki & Sormunen, 2019; Andersson et al., 2020). If only investigating the short-term perspective, it might as well be more costly to spend time on finding components and once they are found they might require treatments and reparations before being reused. Thereby it can be argued that it is cost beneficial to buy new material and/or products (Kärki & Sormunen, 2019). However, if the knowledge is increased, reused components could be used to a greater extent and thereby the availability would increase as well, which consequently would result in a less cost- and time-consuming process (Kärki & Sormunen, 2019; Andersson et al., 2020; Almasi et al., 2020).

Reuse is often associated with *financial value*, as an opportunity to reduce costs by using secondary materials prior to new resources (Nußholz et al., 2020). However, according to Nußholz et al. (2020), this area of the financial value of reused materials and components in a company is not widely explored by researchers. This applies, for example, to prices related to secondary materials and increased cost regarding reversed logistics and labour cost. Another factor can be the regulatory demands of the product that only new materials can meet. However, the economic value of reused building materials and products depends on the whole value chain. Cost factors such as the identification of transport distances, the quantity of materials and site conditions are identified as the factors with the greatest influence on costs (Nußholz et al., 2020).

2.2.2 Reused window components

According to Andersson et al. (2021b), windows are considered to be a component that is relatively easy to dismantle as they can be separated from buildings without significantly destroying or affecting their structural properties. As mentioned in Chapter 2.1 different types of window structure materials have different reuse potential. Windows essentially made of aluminium have a high reuse potential as the material has an energy-intensive reproduction process (Chau & Ng, 2015). Andersson et al. (2021b) conducted a study about reuse of products which resulted in that approximately 90% of the products studied where in the condition of reuse. Their study included windows which showed that the windows functionality was high even though their aesthetic conditions were lowered and approximately 20% of the windows did not have any defects (Andersson et al., 2021b).

Furthermore, in the case of windows, there is a lack of knowledge on how to properly separate the materials that can be reused and also those that are recyclable (NCC, 2020). However, when the Swedish Environmental Institute investigated the subject of reusing construction components, the results showed that from the 15 studied components, windows were ranked as the fourth best alternative (Andersson et al., 2021b). In order to reuse more windows in the construction sector, it is necessary that more actors are involved and willing to cooperate by sharing the knowledge that already exists on reuse and together helping each other to broaden this knowledge (NCC, 2020; Andersson et al., 2021b).

When investigating studies regarding reuse of window components the results differ depending on the project studied and scale of reused windows, even though the majority shows a positive impact on the climate (Andersson et al., 2021; NCC, 2020; Chau & Ng, 2015). Chau and Ng (2015) concluded that the energy savings from reusing windows compared to recycling were about twice as high: reusing provided an energy saving of 48% compared to recycling which provided 26%. In the study conducted by Andersson et al. (2021b) the climate saving potential of reusing windows reached 12% of tonnes of CO2-equivalent.

There are additional aspects to consider regarding the selection of components that can be reused. The Centre for Circular Construction has created a guide called the Building Recycling Guide, to increase knowledge about building materials and components that can be reused in the operational phase. The guide is primarily aimed at private individuals but provides an overview of the conditions under which specific components, including windows, can be reused. The study presents the components based on building materials, which year it was manufactured and installed for use, and the risk of hazardous content. With the help of the guide, it will be easier to choose which windows are suitable and harmless in the operational phase and be able to reduce the health risk. According to the Swedish Environmental Institute, windows are one of the most popular products to reuse on a small scale, i.e., private individuals buy window sections from second-hand shops. (Ahlm, Berglund, Emilsson, Lindholm, Miliute-Plepiene & Unsbo, 2021)

2.3 Circular business model

This chapter regarding ‘Circular business model’ is an important aspect for understanding how companies can reduce their environmental impact by a transition from the linear model to a more circular one. The chapter connects with the previously gathered theory regarding reusing components since reuse, as well as the other steps in the waste hierarchy, are important in order to reach a circular business model.

The Swedish construction sector is facing serious challenges to meet the prevailing construction demands and simultaneously achieve set climate goals of net emissions (Naturvårdsverket, n.d). The construction industry has a considerable impact on the climate, where presented statistics from the National Board of Housing, Building and Planning showed that the Swedish construction sector accounted for 21% of Sweden's total GHG emissions in 2019. Furthermore, 80% of the total emission from the production and construction-phase is accounted for from manufacturing construction materials (Fossilfritt Sverige, 2018). The choice of material is of great importance for how large the emission will be during construction. To reduce the environmental impact, it is necessary to use resources more sparingly, make better use of product life, produce new products from recycled materials and reuse more (Naturvårdsverket, n.d).

The flow of reused materials and components in the construction sector is currently low. For the reuse market to mature, companies and organisations need to restructure their business models to support the challenges associated with reuse (Andersson, Gerhardsson, Lindholm, Moberg & Wennesjö, 2021a). The definition of a business model in the Cambridge Dictionary (2022) is "a description of the different parts of a business or organization showing how they will work together successfully to make money”.

Unlike a linear business model where the focus is on companies achieving economic profitability, circular business models have a broader perspective and also include the two other dimensions of sustainable development, society and environmental (Hofmann, Jokinen & Marwede, 2017; Tillväxtverket, 2021; Nußholz et al., 2020). Along with wider scope of sustainability, this type of business model includes a wider scope of stakeholders (Hofmann et al., 2017). A circular business model signifies that an organisation or company implements processes to capture the value contained in materials and products that would otherwise be considered to be at the end of their life cycle. Figure 3 below shows the basic principles of linear and circular economy. The goal of circular business models is concisely to be able to create economic profitability while reducing their carbon footprint and use of raw materials by focusing on reuse, recycle, recovering and renewable energy (Tillväxtverket, 2021; Mangialardo & Micelli, 2018).

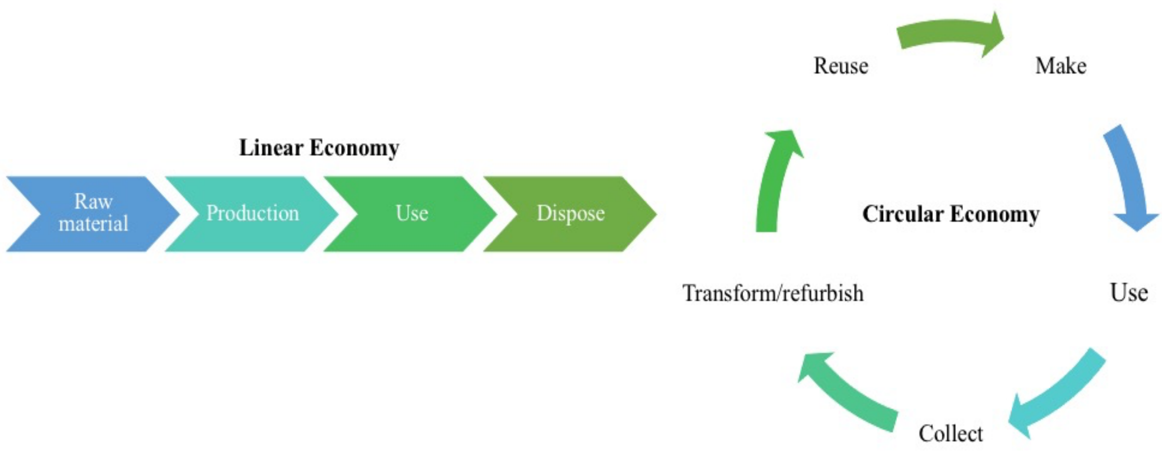

Figure 3. The basic principles of linear and circular economy

The transition to a circular business model requires a change at the organizational risk level, and new ways of thinking and doing business. Through the Sustainability Guide (Hofmann et al, 2017), the previous traditional focus of organizations has changed as more have converted to circular business. No longer is the focus mainly on maximizing profit or lower production cost, instead the focal point is to redesign and structure a product-service-system to ensure the business future success of activities and to align with the competitiveness of the market. (Hofmann et al, 2017)

For circular enterprises, the product use phase is of great importance. Measures and approaches common to circular enterprises are to reassess their activities regarding value creation, relations between producer and consumer, organizational goals, culture and philosophy. These are complemented by social and environmental factors. Hofmann et al (2017) and The Ellen MacArthur Foundation (n.d.) presents the identified typology that contributes to a circular business model as followed:

- Circular supplies: Resources used in production and consumption systems must be delivered as renewable, recyclable, or biological degradable. This with the focus of substitute fossil raw materials.
- Access and performance: Include actions and mindset to provide value and satisfy the users need through capability or services. This with the focus on providing functionality for customers without owning physical products.
- Extending product value: Delivered products must be of high quality and designed in such way that they can be repaired, refurbished, upgraded etc. Where other products would be classified as waste, the value of these products residual value is of importance.
- Bridging: Prioritize cooperation and create communication platforms between producer and consumer, from the individual to the organization level. Cooperation between different, but interdependent, actors to match supply and demand.

When reused materials and products are introduced into a company, the business model must be designed to make the use of reduced materials profitable and competitive from an economic and environmental point of view. At the same time, the materials/products must comply with industry-specific standards and regulations. Business models for reuse is an unused and unexplored model, and according to Nußholz et al. (2020) it could arguably depend on ignorance and lack of knowledge of what impact reused materials/products and circular economy has on the building industry. (Nußholz et al, 2020)

2.3.1 Circularity within the construction industry

The value chain of construction process includes different stages starting with the design of the building where the materials used are being selected, followed by the production process. Furthermore, the value chain does not end once the building is fully constructed, it still must be maintained and occasionally refurbished. Sometimes buildings go through several renovations during its lifetime and the circular economy can be implemented in all of these stages of the value chain (Høibye & Sand, 2018; Comfort & Jones, 2018).

Beukering, Kuik and Oosterhuis (2014) explains that the volumes of waste generated from the construction is not always recorded which makes it hard to evaluate the impact. However, Mangialardo and Micelli (2018) emphasize that approximately 80% of the materials today becomes waste when the buildings lifetimes have reached the end. Even though 80% of the materials becomes waste, only 5-10% of the materials have no value after dismantling the building (Beukering et.al., 2014). A more circular business model would generate benefits for the environment by having the possibility of decreasing the CO_2 emissions by 70% according to Beukering et al. (2014), The Ellen MacArthur Foundation, (2017), Stahel (2016) and Høibye & Sand (2018). Companies would also gain more opportunities for innovation as well as a necessity to have a long-term relationship with other actors in the industry (The Ellen MacArthur Foundation, 2017).

As more focus is put on the design phase in circular economy, or at least should be, buildings and/or components can be designed in a way that makes it easier to repair them when needed (Comfort & Jones, 2018; The Ellen MacArthur Foundation, 2019). However, according to Comfort and Jones (2018) it is not an easy task to introduce more circularity within the construction industry due to its complexity and large numbers of actors and stakeholders involved. According to Høibye & Sand (2018), for the implementation of circularity to increase there is a need of more regulations, e.g., that materials included in a building must be documented together with a demolition plan.

When talking about circular economy within the construction industry the main focus often lays at recycling and waste even though it should focus on the whole value chain. For a structure to be circular, it must be designed from a circular perspective (Comfort & Jones, 2018). This generates other possibilities such as that it is easier to adapt the buildings for other uses areas. The second design principle, designing out waste, means that waste should be seen as an opportunity and thereby transformed into new resources. However, for this to be possible technologies should be used such as pre-fabrication that makes it easier to minimize the waste produced on site as well as BIM or other new technologies. All these suggestions increase the quality of the finished buildings and can also reduce the costs of projects (The Ellen MacArthur Foundation, 2017; Mangialardo & Micelli, 2018).

2.4 Stakeholder Identification

More industry-wide restrictions and regulations have made companies and organisations more responsive and aware of current and future environmental changes. How well the building sector adapt to more climate smart solutions, for instance increasing reuse depends on several factors, one being highly developed and effective cooperation between actors (Balador, Gjerde, Isaacs & Shabahang, 2019; Svenskt Näringsliv, 2019).

To achieve an optimised resource-efficiency and circular economy, cooperation is a key concept. From a broad perspective, societal actors and stakeholders need to act in industrial symbiosis, as what one actor does can have an impact on another actor's opportunities (Høibye & Sand, 2018; Svenskt Näringsliv, 2019; The Ellen MacArthur Foundation, 2017). Industrial symbiosis means long-term working relationships between actors and stakeholders to achieve more efficient use of resources. According to the Confederation of Swedish Enterprise industrial symbiosis has for long existed in Sweden, however mostly in the form of local clusters of companies (Svenskt Näringsliv, 2019). The collaboration should take place between value chains, sectors, and roles such as policy makers, businesses, public sector, etc. By having an established network with other stakeholders and actors, companies can coordinate material flows, and use resources that are considered by-products in other sectors. By using industrial symbiosis as a tool, companies can achieve economic and environmental benefits (Svenskt Näringsliv, 2019).

The complexity to transform the construction industry towards a more climate smart industry, more specifically implementing reused material, is associated to the number of stakeholders. This implementation will result in an identification of the collaboration/dynamics between actors which will lead to the needed change. It is of importance that the involved actors are updated on the current situation to be able to form a strategy. (Balador et al., 2019)

The large-scale reuse-market is currently unestablished on Swedish soil, even though actors, organisations, politicians, and others see value (Andersson et al., 2021a). The construction sector currently lacks the working methods of involved stakeholders and crucial reuse related services/actors to enable scaling up and cooperation between stakeholders in the value chain has potential for development (Andersson et al., 2021a; Balador et al., 2019). Additionally, there is an uncertainty regarding reused materials quality which and thereby specialists within reused components should be involved during the project (Høibye & Sand, 2018). However, it is not enough that the involved actors increase their corporation. Both the supply and demand side must work more closely together as well as an increased acceptance regarding reused components (Comfort & Jones, 2018).

Høibye and Sand (2018) explains that constructors, designers, waste managers and demolition companies must work more closely together in the early phases to solve problems that can occur later during the project regarding logistics and warehousing of materials. As can be seen, there are several different stakeholders that need to be involved in the early stages of increasing the number of circular businesses and reuse in the construction sector.
The key stakeholder identified during the theoretical framework is:

- Client
- Architect and/or Designer
- Contractor
- Reuse Centres and/or Reuse Consultant
- Dismantling contractor/company
- Politics and Society

In Chapter 2.4.1-2.4.6 below, identified stakeholders for implementing reuse are presented, together with their particular responsibilities, hinders and opportunities in terms of development.

2.4.1 Client

The client can be seen as the developer and/or property owner, i.e., the clients buy the land where the building will be constructed, makes sure to raise the funds so that the project can economically be carried out as well as carrying out the project. A client can be seen as the actor who have the greatest responsibility and influence on increasing reuse activities (Ferrando, Hemström, Horkmans, Juez, Lindblom, Lisbona, Matejczyk, Monero, Palm, Ratman-Klosinka & Trinius, 2012). Andersson et al. (2021a) point out that the internal structure of the client is not clearly developed, i.e., whether the client should be responsible for the inventory of reused products and storage or whether it should be handled externally by another actor. What they point out is how essential it is for the client to have the expertise in how to formulate the requirements for reuse towards contractors and suppliers in tenders and orders for the conditions upstream of the "reuse chain" to be optimal (Andersson et al., 2021a).

Reusing components have been met by a resistance from the client in some studies, mainly due to the additional risks (Gorgolewski, 2008; Andersson et al., 2021a; Miliute-Plepiene & Moalem, 2020). Implementing reuse can be a costly process that requires selective demolition, larger storage areas and more time to find the reusable components. As many projects are prioritized in terms of schedule and cost, numerous times this leads to clients often being unwilling to risk these additional costs (Ferrando et al., 2012; Gorgolewski, 2008). Overall, building with reused products might be a time-consuming process and thereby requires strong commitment and management from the client (Gorgolewski, 2008; Ferrando et al., 2012). The client should be inspiring the rest of the project team of the opportunities generated by reusing components where the commitment is necessary to overcome those barriers related to costs and time schedule. The process of reusing components goes beyond the traditional way of working and thereby the client must adapt to the changes, both in the early stages of the procurement process as well as in the general construction of the building where hinders can occur (Gorgolewski, 2008). Both the economic and environmental value of reused components must be factored into project and investment calculations to even make it competitive compared to newly produced building components. This would create internal incentives so that reuse would be seen as a potential resource and not just a cost to the company. There is no suggestion of how this should be done as it should be up to each company and their system to account for it (Andersson et al., 2021a).

Resistance may also be due to a lack of knowledge, both about the benefits of reusing components and about how to overcome the aforementioned obstacles. The customer and/or client is often unaware of the environmental benefits of reusing components, which is one of the main reasons for reuse. Since these components might not have the same guarantees or quality as newly produced products have the client, in some cases, does not have the proper knowledge of how to make the quality assurance (Ferrando et al., 2012; Balador et al., 2019. According to Ferrando et al. (2012), studies show that due to a lack of knowledge regarding the reuse of components, some clients did not believe that they could be responsible for leading the work and thus transferred most of the knowledge and responsibility to architects and/or design firms. However, as the process of reusing components must start early in the project even before a contractor has been hired, the client must be responsible for finding and purchasing reused components (Gorgolewski, 2008). This process has to start before designers and/or architects can design the upcoming projects, as they need to know if the components will even be available on the market (Gorgolewski, 2008; Ferrando et al., 2012). For the market of reusable components to be able to grow, it is not only important that companies use reusable products in new projects, but new methods and techniques are needed to select materials without damaging them if a building is to be demolished. This process both requires knowledge as well as time (Gorgolewski, 2008). Andersson et al. (2021a) emphasizes that the willingness from the client's side to implement reused components will be increased if their knowledge regarding the environmental benefits would be increased as well. However, Andersson et al. (2021a) also suggests that stricter demands and requirements are needed to report the operations environmental impacts which would serve as a mechanism to increase reuse.

2.4.2 Architect and Designer

The architects and/or designers have a crucial role in the construction industry and the implementation of a more circular business of reused material and components. As a valuable and influencing stakeholder they can improve the attitude towards reuse in design (Balador et al., 2019; Ferrando et al., 2012). Architects are too seen as reliable consultants regarding green issues (Ferrando, et al., 2012).

Today, architects carry out projects which encounter reused products, although mostly in the form of cultural values that need to be considered for the purposes of preservation. However, according to Balador et al. (2019) and Ferrando et al. (2012), architects are getting more willing to adapt their working methods for implementing reuse in projects. The motivation seen in increased reuse for architects is aligning with the motivations for other stakeholders; reduce their climate impact, increase profit, and improve the reputation (Balador et al., 2019). The value that architects can create for clients/developers is by identifying existing quantities of reused components that can be economical, environmental, quality, and aesthetical competitive to newly manufactured products and components (Andersson et al., 2021a).

Even though the architect is seen as an important stakeholder, the client/developer is considered by architects to be the actor that enables them to carry out work with reused components. The client should include reuse as a requirement in the tender and project requirements, after which the architects can act. This is of significant importance due to the uncertainties regarding warranties, quality assurance, procedures and the currently limited supply of working with reusable components. Nevertheless, this current situation also makes it unmotivating for architects to try to persuade the client to implement reuse in project documents. The architects with the right motivations and broad knowledge of reuse should be included in early decision making together with other stakeholders, clients, and contractors, to create the right conditions for their design ideas. (Balador et al., 2019; Andersson et al., 2021a).

As the existing offer of reused components is limited, architects' working process will probably become inverted and their creativity hindered. Architects will have to start with the inventory, control and safety standards, regulations, etc. to later implement these “building-and dismantling waste” into valuable products (Balador et al., 2019; Ferrando et al., 2012). According to Andersson et al. (2021b), the inventory should start by evaluating the existing building stock and demolition projects, which might not be as attractive to architects compared with newly manufactured components. With this said, the architects might need to change their habits and attitude of what is considered attractive in new constructions (Andersson et al., 2021a).

The inverted working process can become time consuming, and as a result, a more manageable timeframe and appropriate budget should be aligned with what is needed for the architects to perform this (Balador et al., 2019; Andersson et al., 2021a). Additionally, knowledge barriers are considered a major challenge for the architects as well (Balador et al., 2019; Ferrando et al., 2012). They will need expertise in the environmental benefits, technical possibilities, to be able to offer the advanced reuse solutions needed for an optimal supply chain (Ferrando, et al., 2012)

According to IVL’s study (Almasi et al., 2020), architects had a common view on the lack of an established circular flow or reuse of resources, which currently makes reuse suitable only for premises and/or renovation projects. Even though reuse is only seen compatible with these types of projects, architects believe that this could be a strong start for the future development of reuse in larger projects (Andersson et al, 2021a). According to Ferrando et.al (2012), what would enable more reuse in the future would be to implement the practice of DfD, which would increase the possibilities for extracting valuable materials and components to be reused in new production. This is not widely reflected in the working habits of architects today given the need to reconstruct the whole sector (Ferrando, et al., 2012)

2.4.3 Contractor

Andersson et al. (2021a) express that contractors have a crucial role in the restructuring of the construction sector to enable a large-scale reuse market. The authors also stress that there is a lack of services in the sector to meet the demand, and these services are largely lacking amongst the stakeholders who provide physical handling of reused products, and there too the contractor is a dominant player. According to Andersson et al. (2021a) and Ferrando (2012) there is a tendency for contractors not to show the same commitment and uptake of reuse-related services compared to actors further down the value chain, i.e., architects, consultants and property owners. This due to lack of knowledge about these components/products, which seems to complicate processes handled by contractors. (Ferrando 2012; Andersson et al., 2021a)

What is observed today is that the client does not adapt the contractual requirements to enable reuse, which makes it difficult for contractors to work with this particular issue. How contractors are allowed to carry out their work is entirely dependent on the form of contract and the requirements set out when contracting with the client. Therefore, contractors consider themselves as being a more passive "player" in the question of increasing reuse and need to see initiative from the client in order to be able to carry out reuse-related services themselves (Andersson et al., 2021a; Ferrando et al., 2012).

Although a major adaptation and change needs to take place across the sector, Andersson et al. (2021a) believe that individual contractors need to do an internal investigation on their activities which should commit to reuse. Management of what is considered end-of-life materials and products is currently a blurred and overwhelming part of the construction process, which could be facilitated by stricter requirements for reuse within the specific organization. Then the specific organization/company can achieve certain environmental goals and, in this way, also inspire and lead the change for other stakeholders (Ferrando et al., 2012; Andersson et al., 2021a).

The surveyed contractors, according to Ferrando et al. (2012), did not experience any major setbacks in the installation of the reused components, but problems were encountered earlier regarding the supply of the components. The craftsmen or subcontractors will probably need to undergo special training to carry out installations of reused components as these may differ with the standards that new construction products may have (Ferrando et al, 2012).

Furthermore, larger contractors are today facing a challenge as the one responsible for ordering materials and building components where there is a need for an industry-established tool, preferably a website, that can give the opportunity for contractors to secure the material needed. Contractors should also maintain good cooperation with several of the hopefully future participating actors, such as dismantling companies, resellers, recycling consultants, etc. Another challenge that has been previously mentioned in Chapter 2.2.1, is the lack of guarantees and classifications of reused products, which also affects contractors and their attitude towards reuse (Ferrando et al., 2012).

2.4.4 Reuse Centres and/or Reuse Consultant

A reuse centre is a company that acts as a reseller of different building materials and other reused products as well. The reuse centres are available for both the private individuals and companies even though a majority of the customers are private individuals (Ferrando et al., 2012; Andersson et al., 2021a). According to Ferrando et al. (2012) there were 20 reuse centres in Sweden in 2012 which all operated to a lesser extent under commercial or public conditions. The products resold at the reuse centres are not repacked or quality checked which the buyer is responsible for doing (Ferrando et al., 2012). However, there is an increasing desire from actors within the industry that reuse centres should expand their services and resell products that are quality assured so that guarantees can be applied similar to CE marking, EU basic health, environment and safety requirements (Andersson et al., 2021a). The desire lies not only in the quality perspective, but stakeholders also see opportunities for cooperation between different reuse consultants and/or centres. In the study carried out by Ferrando et al. (2012) suggestion was made regarding a common website that publishes the different reused components available as well as information about it. Since the product information, such as component sizes, mut be known prior to the construction project start a website would increase the possibilities of finding these components (Ferrando et al., 2012).

According to the study conducted by Ferrando et al. (2012) waste management companies emphasizes that the is a need of a new actor within the construction industry, in the form of a reuse consultant to achieve reuse in a larger scale. The main focus for this role would be to specialise in handling, storage, reconstruction and selling of reused components. As for today, reuse agents and/or traders are smaller companies that sett most of what is sailable. However, these are often seen connected to the municipality´s recycling and/or reuse centres (Ferrando et al., 2012). As mentioned, the reuse actor would work with the reconstruction of the reused materials, since this often is a necessary step before the products can be reused. Remanufacturers can offer refurbishment and processing of lower quality rejects so they can compete with new production, considered an important player in the value chain (Andersson et al., 2021a). How well the product can compete with the price of new production depends on whether it can still be priced lower after remanufacturing. Andersson et al. (2021a) describes that today, there are remanufacturers in the installation industry linked to certain products that are considered to possess high values and justified to be remanufactured. Bricks are also an example of materials that are available from building materials stores as reconditioned for resale. This proves that there is an opportunity to establish reconditioning services for reuse, but for which material and product is determined by demand and willingness to pay.

When discussing the reuse of components to a larger scale there is a need to bring in the aspects of warehouses and storage facilities. This is mainly due to that when reusing components, they cannot be reused directly and must be stored in some sort of facility. The warehouse costs are the biggest expense connected to reusing. To keep that cost as low as possible, the sold reused components must have as high revenue as possible. It is the client that will pay for the time that the reused material must be stored, and it is also important to consider the geographical location to the storage facilities to minimize transportations. Activities for warehouse keepers to promote the inflow could be available containers at reuse centres, contracts with contractors, dismantling contractors and real estate owners/developers as well as a close communication and collaboration with building materials trade and building material manufacturers. The storage space must also be adapted to the inflow of reused components which can be considered as a challenge due to the unknowable future of supply and demand. (Andersson et al., 2021a)

The storage facilities can be either privately or municipality owned. The challenges that can occur if they are privately owned are that they have demands on economic feasibility were as municipality owned can be subsidized and create another type of social benefit, like decreased waste and environmental impacts as well as creating more simple job opportunities. However, regarding municipality owned are certain legal restrictions in the form of them not being allowed to conduct activities outside the municipality. Furthermore, municipal actors see their initiatives as temporary while waiting for the private business sector to take over and drive the market for reused and/or recycled ancillary services further. (Andersson et al., 2021a)

One of the obstacles that might hinder a wider implementation of reuse centres are the poor cooperation between different reuse agents as well as the aspects of guarantees. Guarantees are often not included in reused products which means that other actors within the industry does not want to take the risk of using these products. It can also be hard for reuse agent to guarantee accurate information regarding the products such as the component size (Ferrando et al., 2012). The valuation of reused products requires that the consultants have access to all information on the products and that the calculation is credible. Using data from environmental databases and evaluation tools to quantify the value, consultants can compare a reused component with a new one, and thus make a valuation. However, it is considered that valuing them is an industry-wide responsibility and would facilitate the introduction of reuse. (Andersson et al., 2021a).

2.4.5 Dismantling

An important role in a conversion to buildings circularity and increased reuse is the dismantling, also called deconstruction. In short, this means that you are constructing a building in reverse, by dismantling the building without causing too much damage to materials and components that could possibly be reused in new projects. However, today demolition is used more widely. Demolition is a relatively destructive but less time-consuming method, where a building is demolished, creating waste of a more manageable size to be sent to landfill or recycled (Bertino et.al. 2021). The aim of dismantling buildings is to drastically reduce the usage and consumption of virgin materials and non-renewable construction materials (Ferrando et.al. 2012 and Kuhelen).

In both Andersson et al. (2021a) and Ferrando et al. (2012) studies, the driving factor for demolition companies to increase their reuse processes is regulations and landfill taxes. This will push the economic initiatives for the companies, as they would avoid waste along with the charges for it and would gain profit. Due to the already existing landfill taxes and regulations, there is today a workable routine of sorting out the products and material in demolition, and the interviewed demolition companies in the study by Ferrando et al. (2012) believe that it would not require excessive extra work to carry out a more accurate sorting for the purpose of reuse. Additionally, a good functional network of partners who sees the economic interest in products needs to be established (Andersson et al., 2021a).

Today it is seen that some dismantling companies are including reuse in their tender calculations and are selling the material that they can, through different internal networks. However, this has not yet been as financially defensible business on a larger scale (Ferrando et al., 2012). According to Andersson et al. (2021a), the demolition company can, and do to some extent today, sell some of the dismantled products, and by doing so generate revenue and if the products/materials are donated, waste fee is avoided. This is a possibility for the demolition contractors to sell even though it might not be stated in a contract. The actors willing to pay are usually smaller building contractors or other retailers (Andersson et al., 2021a).

One of the challenges that the demolition companies are facing is the lack of time for dismantling instead of demolition, even though it can be seen as a profitable execution (Andersson et al., 2021a; Ferrando et al., 2012). This along with the time to advertise the available materials in the network of actors. According to Andersson et al. (2021a) and Ferrando et al. (2012), to enable the dismantling businesses to perform a profitable business, the requirement from the client needs to be generous with giving enough time, along with the extra cost for dismantling as it is a time-consuming process as well as clients and/or contractors make an order on the material in advance. This means that the dismantling company and the cost of hiring them needs to be involved early so the work is clear and the cost can become more defendable (Andersson et al., 2021a; The Ellen MacArthur Foundation, 2019).

In both Ferrando et al. (2012) and The Ellen MacArthur Foundation (2019) the importance of education and execution of working routines before starting the dismantling is crucial. What the demolition companies have seen is that some components are easier to dismantle, such as doors and windows, because the attachment mostly looks the same throughout one building. Although the attachments can be known for one building, older buildings often show the tendency of having attachments that are harder to dismantle which can result in damage to materials and components, thereby reducing the possibility of reuse. According to Ferrando et al. (2012) study, many other stakeholders/actors see the demolition companies as the stakeholder who makes the final decision if a product is reusable or not, as they often are the only ones at the site when the demolition/dismantling process is executed.

2.4.6 Politics and Society

Throughout this study, a number of stakeholders and the difficulties they face related to increased reuse have been presented. Since stakeholders, actors and professionals within the construction industry have problems to overcome these barriers there is a need to implement policies and new regulations regarding reused components. The request for reused materials is highly connected to politics and the preferences of the different actors in the building industry. How the market of reused material/components shapes itself depends on actions and decisions on a society level. If preferences are shown on increasing the use of this type of materials it would most likely influence the organizations to meet this demand. (Balador et al., 2019; Høibye & Sand, 2018; The Ellen MacArthur Foundation, 2017)

Regulations are a great force to encourage increased production of climate- and energy friendly buildings. In addition to new regulations etc., Balador et al. (2019) presents two practices that could affect more actors to reduce the recovery of new materials as well as landfill waste. Firstly, an introduction of a specific tax, "landfill tax", that creates a cost for the organization/contractor when sending waste at landfill. Another motivation would be governmental contributions for construction companies that increase their use of reused products. This would as Balador et al. (2019) states, "result in *input substitutions* and *output reductions",* which implies by using less new resources and instead use substitute material such as reused product and material, will result in a smaller waste output.

Furthermore, in order to generate necessary changes, Wilson (2007) and Balador et al. (2019) clarifies the importance of public awareness and education. As the public play an important role in the eyes of politics, the effect of the society and the behaviour of the public, will influence political decisions.

2.5 The process of Prefabrication

All the previous theory presented in the theoretical framework can be generalised for the construction sector, and thus can be applied to industrial construction, which in this chapter is preferred as prefabrication. The theory presented above will be linked to prefabrication in the discussion. This chapter will present how the construction process prefabrication works in practice, its advantages, and limitations.

Prefabrication is an off-site construction method where building modules are manufactured in a factory before it is sent to the construction site for on-site installation (Doran & Giannakis, 2011; Hewage & Kamali, 2016; Li, Shen & Xue, 2014; Dong, Liu & Sheng, 2020). Prefabricated modules can vary from consisting of partial assembly of components, i.e., finished wall elements to complete volume modules furnished with various fixed installations (Li et al., 2014; González, Khan, Lim, Masood & Roy, 2022; Jian, Jingke & Ruoyu, 2020). By prefabricating, the construction process is streamlined and requires significantly less time for installation on-site. Prefabrication is today seen as a business strategy for sustainable and affordable production of buildings, which benefits the economy, society, and the environment (González et al., 2022; Jian et al., 2020).

Prefabricating modules has during the past years increased in the construction industry mainly because of the advantages that the methods prove to contribute with (Li et al., 2014). Advantages that are not mentioned in Table 2 below include reduced consideration of weather conditions, theft and vandalism, which are factors that are less problematic when the majority of work is carried out in factories (Hewage & Kamali, 2016).

Table 2. Advantages from using prefabrication

Advantages	**Description**	**References**
Decreased construction times	Higher efficiency and productivity	(Doran & Giannakis, 2011; Eltoukhy et al., 2021; Jian et al., 2020; Molavi & Barral, 2016)
Reduced costs	An aspect that is affected by all of these advantages	(Doran & Giannakis, 2011; Dong et al., 2020; Hewage & Kamali, 2016; Li et al., 2014; Jian et al., 2020; Molavi & Barral, 2016)
Sustainable	Less waste, dust, and noise. Decreased GHG emissions and energy consumption	(Eltoukhy et al., 2021; Dong et al., 2020; Hewage & Kamali, 2016; Li et al., 2014; Jian et al., 2020; Molavi & Barral, 2016)
Higher quality	A more controlled environment within the factories	(Eltoukhy et.al., 2021; Hewage & Kamali, 2016; Li et al., 2014; Joan et al., 2020; Molavi & Barral, 2016)
Higher safety	Can be increased by 85% in comparison to on-site construction	(Eltoukhy et.al., 2021; Hewage & Kamali, 2016; Li et al., 2014; Joan et al., 2020; Molavi & Barral, 2016)

Sustainability is a broad category of advantages. For instance, the construction time decreases and thereby decreases the energy consumption during the construction process. Since less time is spent on-site, less noise and dust are produced which can be connected to the aspects of social sustainability and will not disturb the surrounding neighbourhood to the same extent as traditional construction (Eltoukhy et al., 2021; Dong et al., 2020; Hewage & Kamali, 2016; Li et al., 2014; Jian et al., 2020; Molavi & Barral, 2016). In addition, prefabrication does not generate as much waste because the design phase is more complex and elaborated and the purchase of materials is to a greater extent standardized. When the modules are manufactured, many of the steps are done using machines that make cutting and sawing more precise, generating less scrap (Hewage & Kamali, 2016). Other aspects that favour the durability of prefabrication are the fact that at the end of the life of the buildings, the modules can be more easily dismantled. This in turn increases the possibilities for reuse and recycling, and if desired, the modules can be moved to other sites and other projects. (Hewage & Kamali, 2016). All these factors make prefabrication a more environmentally friendly method of reducing GHG emissions. (Hewage & Kamali, 2016; Dong et al., 2020).

By using prefabrication method, the final costs of the project can be reduced (Doran & Giannakis, 2011; Dong et al., 2020; Hewage & Kamali, 2016; Li et al., 2014; Jian et al., 2020; Molavi & Barral, 2016). According to Hewage and Kamali (2016) the construction time can be reduced by 40% which consequently will decrease the project costs. Exactly how much money can be saved by using prefabrication depends on the scope of the project, but Hewage and Kamali (2016) emphasizes that there are studies showing a 10% reduction in overall costs and up to 25% savings in on-site labour costs. Cost benefits also depend on other factors such as how well a process is standardized and energy efficiency (Hewage & Kamali, 2016).

Furthermore, the modules are built in factories, which is a more controlled environment and benefits the quality of the modules themselves as well as the overall project (Eltoukhy et al., 2021; Hewage & Kamali, 2016; Li et al., 2014; Jian et al., 2020; Molavi & Barral, 2016). The manufacturing is standardized and can thereby be considered as a more repetitive process where most of the work is conducted by automated machinery and thereby decreases the risks of human errors related to the quality. The quality can also be a factor connected to safety which is another advantage (Eltoukhy et al., 2021; Hewage & Kamali, 2016; Li et al., 2014; Jian et al., 2020; Molavi & Barral, 2016). According to Hewage and Kamali (2016) the accidents rate on the construction site are slowly decreasing within the construction industry, however, by making most of the work in a controlled environment in the factories the safety can be improved by 85%. When manufacturing the modules, the workers have smaller tasks throughout the assembly lines and the learnings time are fast which both causes less damage to the products in the factories as well as increasing the safety (Eltoukhy et al., 2021; Hewage & Kamali, 2016; Li et al., 2014; Jian et al., 2020; Molavi & Barral, 2016).

Although there are proven cost benefits of prefabrication, the cost aspect can also be a barrier and a challenge. The barriers of costs and the others found can be seen below in Table 3. As mentioned above, prefabrication has received more attention in recent years, but it is still not used on a large scale where cost plays an important role (Hewage & Kamali, 2016; Eltoukhy et al., 2021). In order to implement prefabrication methods within a company there is a need for an initial capital to get the process started. These costs are often related to, among other things, the advanced machinery and extensive factory space required (Hewage & Kamali, 2016). In addition, there is a lack of knowledge about the method, which makes companies hesitate whether it is worth changing their current business model or not (Eltoukhy et al., 2021).

Table 3. Key challenges and barriers for implementing prefabrication

Challenges/barriers	**Description**	**References**
The complexity	Intensive planning. Important with good communication	(Eltoukhy et al., 2021; Hewage & Kamali, 2016)
Design	Hard to make changes later on during the project	(Eltoukhy et al., 2021; Hewage & Kamali, 2016)
Logistics	Strict project schedules and deliveries. Need of good communication and management	(Eltoukhy et al., 2021; Dong et al., 2020; Hewage & Kamali, 2016)
Costs	Need for an initial capital to start the process as well as for buying machinery and factories.	(Hewage & Kamali, 2016; Eltoukhy et al., 2021)

Prefabrication can be considered a more complex process as it requires rather intensive planning before the start of the project. This is because once the process in the factory has started it is complicated to make changes (Hewage & Kamali, 2016). The higher complexity is especially connected to the design stage where many factors must be well thought of (Eltoukhy et al., 2021; Hewage & Kamali, 2016). The modules design should minimize the generation of waste as well as being designed in detail and for the potential of a lean production (Eltoukhy et al., 2021; Hewage & Kamali, 2016). During the whole project process there is an increased need for coordination and communication in all of the project phases and involved actors and stakeholders (Hewage & Kamali, 2016).

The complexity of using prefabrication is one of the barriers mainly connected to the logistics where deliveries and transportations must be done in time (Dong et al., 2020; Eltoukhy et al., 2021; Hewage & Kamali, 2016). Regarding transport, there are two aspects to consider. If delays occur, it will have a negative impact on the project schedule, which will affect costs (Dong et al., 2020; Hewage & Kamali, 2016; Eltoukhy et al., 2021). However, if the deliveries are to early that might also cause problems related to lack of space on the construction site which can generate additional storage costs (Dong et al., 2020). Due to these facts, using prefabrication is dependent on elaborated management and communication which consequently is dependent on a reliable project schedule (Dong et al., 2020; Hewage & Kamali, 2016; Eltoukhy et al., 2021).

3 Methodology

This chapter describes the methods used to answer the research questions of the thesis. First of all, the design of the study is from an audit perspective of a company in the prefabricated wood building industry, a description of the case is presented in Chapter 3.1 below. The study consists of three qualitative parts: a theoretical framework, a case study consisting of interviews and a field study, whereas the theoretical framework and interviews contributed to most of the findings. Figure 4 below presents a schematic of the work process.

The reason for why a qualitative research method were chosen is due to it providing an in-depth understanding of both theory and experiences. In contrast to a quantitative research method which mainly is about analyzing numbers, qualitative research methods are helpful when investigating why things are in a certain way by providing an in-depth understanding of both theory and experiences (Institute for Work and Health, 2011). For the literature study, the selection of the chosen sources formed the basis of knowledge about reuse, the reusability of windows and the identification of stakeholders involved in the implementation process. Furthermore, the subchapter regarding the interview study presents the process of selecting the respondents along with information about the structure of the interviews. Ethical considerations applied for the interview study is also presented.

Finally, a validation of the thesis and work processes is also presented based on four principles that examine the credibility, transferability, dependability and confirmability.

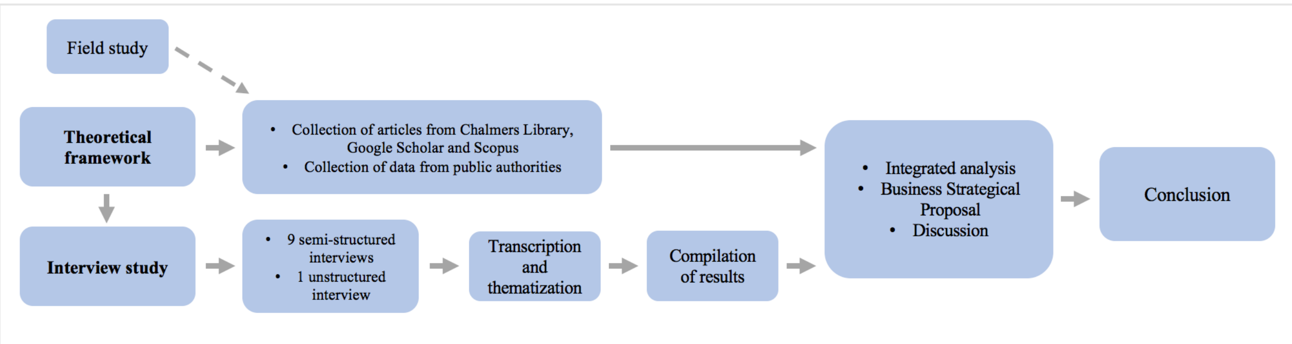

Figure 4. Schematic of the work process and methods used.

3.1 Case Description

The thesis was carried out in collaboration with Derome, which also provided a supervisor. Derome was founded in 1946 and have their headquarters in Veddige, Varberg. At the moment Derome has 2500 employees and is the largest family-owned company within the wood industry in Sweden. Furthermore, Derome follows several of the FN's sustainability goals with a specific focus on four areas within Agenda 2030. These are equality, sustainable consumption and production, sustainable cities and communities and combating climate change. The Derome Group consists of a number of different business areas with different focuses. These consist of Derome Timber, Construction and Industry, Wood Technology, House, Real Estate and finally House Production (Derome AB, 2020). Derome House Production is their industrial production of homes and is the part of the company that has been involved in this study.

Based on a shared interest in environmental issues and reuse, this thesis has been composed to increase knowledge about the reusability of windows and how it can be applied in business models such as Derome's house production through prefabrication. In order for companies to reduce their carbon footprint and hopefully meet future stricter regulations and requirements, Derome is interested in knowing about the possibilities of reusing windows in their production of prefabricated house volumes. Knowing that windows are climate damaging to produce as well as a complex building component, they believe there are many circumstances to explore before implementation becomes possible.

The studied company organised a field study in the house production factory, which consisted of a guided tour and unstructured interviews with Craftsmen A and B further explained in Chapter 3.3 below. As the knowledge of prefabrication was limited before the start of the report, the understanding of the working method became clearer and facilitated further report work. Observations done during the field study consisted of as follows. The factory process goes from simple wooden planks to a volume which is a whole component ready to be assembled into the finished complex building. In the volume, the electricity is drawn, the walls painted, the floors laid, the kitchen cabinets fixed, the shower screen and washbasin installed. The whole process takes place on a physical assembly line where every step is time-optimised, and up to 25-30 volumes can be produced during a week. Therefore, it is essential that the working methods are standardized to make the production more efficient.

3.2 Theoretical Framework

The first type of method used in this research was a literature review. There are different types of literature studies and the one used was a systematic review, as it investigates the current known facts to minimize biased information and in order to answer a specific research question, see Chapter 1.3 (Snyder, 2019). Literature was found in scientific articles, reports, and books in databases such as *Google Scholar*, *Scopus*, *Research Gate*, *ScienceDirect* and *Chalmers Library*. Publications from the Swedish Environmental Institute (IVL) and CCbuild have constituted a significant part of the facts collected. These organisations conduct a significant amount of research related to circularity and reuse in the Swedish construction industry, which was considered appropriate for the limitations and design of the work. All of the sources used was analysed and compared from a source-critical perspective to make sure that the information is up to date and not biased (Snyder, 2019). Reports included were published between the years 2002-2021 and was sorted out by relevance to the research questions.

In addition, public publications from the EU and Sweden as well as reports and other information from actors, authorities and research institutes were used. The aim of the literature review was to provide information and knowledge in an efficient way, as it gives a broad overview of different literature perspectives (Snyder, 2019). Furthermore, the literature study did form the basis for the *stakeholder analysis* and the interview questions.

Parts of the literature study have a more generalized view towards the construction sector, than specifically towards the perspective of prefabrication. Literature presented is carefully selected with the mindset and aspect that it should be applicable to industrial construction/prefabrication later in the study. In the discussion and analysis, all the theory from the literature study is applied to a result directed at companies with the business area of prefabrication.

Furthermore, to build on the facts and information found in the literature study, and to prove or disprove what it presented as well as to gain the perspective of prefabrication, an interview study was conducted. This is presented in Chapter 3.3 below.

3.3 Qualitative Interview Study

Interview studies are a method of collecting qualitative data and can be in the forms of unstructured, semi-structured or structured interviews. The purpose of the interview study is to build up on the already existing knowledge from the theoretical framework, with the theoretical knowledge of the interviewees based on their experiences within the industry (Crabtree & DiCicco-Bloom, 2006). In the case of this thesis, one unstructured and 9 semi-structured interviews were conducted. According to Crabtree and DiCicco-Bloom (2006) an interview is never fully unstructured even though the structure can be compared to a guided conversation. The format of unstructured interviews is mainly used during e.g., filed studies and other sorts of observations (Crabtree & DiCicco-Bloom, 2006). When it comes to semi-structured interviews these are conducted with the help of questions that has been prepared beforehand as well as with questions that arise during the interview. The interviews were not conducted as group-interviews since the aim were to get personal experience and knowledge from each respondent without being affected by other respondents' answers (Crabtree & DiCicco-Bloom, 2006).

The interviewees are found based on information previously found during the project and the ones considered important to interview were called key informants (Crabtree & DiCicco-Bloom, 2006). In the case of this master thesis, in total, 10 interviews were conducted with actors linked to Derome's business and internal operations. However external stakeholders who were considered important for the case study was included after identifying these roles in the literature study. The people who have been interviewed have interest in increasing the reuse of windows and/or may play an important role in the implementation of these in the future. The *snowballing effect* became useful, where the interviewees were able to recommend suitable candidates to further interviews. The interviews were conducted from mid-March to the end of April 2022. The respondents were contacted via e-mail and no interview questions were sent to them in advance, with the purpose to receive as spontaneous and truthful answers as possible. All interviews were semi-structured and conducted individually with the respondents, with the exception where one unstructured interview with Craftsmen A and B took place jointly during the field study. The length of the interviews varied between about 30 to 60 minutes and 7 of 10 interviews were conducted through the digital collaboration tool *Microsoft Teams* and the remaining physically.

An interview guide was designed as a basis for the interview questions. The questions asked concerned possible difficulties in reusing windows to get an idea of the feasibility of reusing these components, as well as questions about which actors need to be driving the issue for the implementation to be successful. Finally, questions were also asked about how the process of prefabrication needs to be changed and/or what methods need to be applied in order for reused windows to be applied in such a standardised and change-sensitive process. The answers to these questions gave an idea of what business strategy suggestions are needed for companies with a business in prefabricated production. The majority of the questions were the same for all respondents, however a few interview questions differed as they were tailored to the respondent's specific professional role. The interview templates can be found at the end of the report in the Appendix. The design of the questions took place during the literature study, in order to be able to design appropriate questions more easily and for the questions to be able to answer the purpose of the study. The interviews were conducted in an as neutral a manner as possible to not evaluate which answers were considered better than others. Table 4 below presents the respondents, together with interview dates and specific interview length.

Table 4. Key informants and respondents

Title in report	**Length of interview**	**Date**
Architect A	30 min	2022-03-23
Architect B	30 min	2022-04-20
Client	45 min	2022-04-08
Contractor A	30 min	2022-04-01
Contractor B	60 min	2022-04-12
Craftsmen A & B	30 min	2022-03-23
Designer	30 min	2022-04-12
Platform Owner	30 min	2022-03-23
Reuse Centre Manager	55 min	2022-04-04
Senior Window Adviser	50 min	2022-03-24

Description

Architect A-Works as an A-Designer at Derome, where the respondent's responsibilities include sales and product development and investigation of daylighting and fire issues. Architect A's work begins when the client delivers the purchased land for the desired project until the building permit is issued.

Architect B- Has worked at Liljewall as an architect since 2011, however, for the last two years the respondent has been working on issues related to sustainability and the environment. Architect B has always been interested in sustainability and has studied Miljöbyggnad which is one of the most sought-after certifications in Sweden.

Client- Currently works as a Division Manager at Derome Bostad and is responsible for sales and pricing of what Derome builds and sells, as well as the construction department among other things. The work consists of the whole process from obtaining access to the purchased land and detail planning to handing over the keys to the customer and in between collaborate with several different involved actors. This respondent is interviewed as the role of the customer, despite the fact that in Derome's business model they act only as the temporary customer and the end customer (for instance the homeowners in the form of private individuals) is the official customer.

Contractor A- The respondent works as a circular manager on the building side of one of Sweden's largest construction companies, and works, among other things, with issues related to waste management and reuse. This contractor has been a part of a project that focuses on recycling outdated window components, as they have identified difficulties with the circularity of these particular components.

Contractor B- Site manager for RA Bygg and has been a part of Derome's project ´Hoppet´ where RA Bygg were one of the major subcontractors.

Craftsmen A & B- Working in Derome's house production factory, assembling house modules that will become apartment buildings. The craftsmen worked at the window station and took care of the attachments and installations of these.

Designer- Designer/project engineer at Derome where the plan elements are manufactured, and the respondents has worked within the construction industry for approximately ten years.

Platform Owner- Works at Derome and is responsible of building systems that creates the house-modules that is being manufactured in Väröbacka and Kristinehamn. Responsibilities includes working at developing Derome's building methods to make it as efficient as possible.

Reuse Center- Head of units at the reuse center in Gothenburg, where one of the responsibilities is to assist and plan for other recycling/reuse centers as well.

Senior Window Adviser- Senior window advisor and product specialist at Svenska Fönster. As the role of window advisor, the respondent works with questions regarding laws and regulations, sustainability, noise, fire safety and building regulations. In addition, the respondent is responsible for providing training to building material dealers, customers, etc., as well as giving advice on optimal window sizes, fittings and glazing requirements.

3.3.1 Ethical Considerations

For this master's thesis, certain ethical principles have been taken into account in order to assure that information about the interviewees was handled correctly.

The interviewees were informed about the nature of the work being done and what their role could bring to an interview. Each interviewee was asked at the beginning of the interviews if they approved of their participation in the paper, consented to the recording of the interview, and if they preferred to be anonymous or not in the paper itself. Out of respect for the interviewees and to reduce the handling of personal data, we chose to exclude their names from the report and minimized the description of their work role.

3.4 Reflections about Validation

To evaluate the credibility of a qualitative study and its results, four criteria should be evaluated and kept in mind. These four criteria are according to Shenton (2004):

- Credibility
- Transferability
- Dependability
- Confirmability

Credibility is how well the results match reality, and according to Shenton (2004) is perhaps the most important of the factors to ensure. In terms of credibility, the study has made use of several interviews with different actors and theoretical data has been collected from several different sources. By collecting information from different perspectives, the results are ensured with greater certainty. Shenton (2004) also points out that a random selection of respondents may be to the work's advantage in order to minimize accusations of bias in the choice of participants. This approach was used for some of the respondents as the study used a *snowball effect* where a respondent could suggest a type of role that should be included for the benefit of the study. Triangulation is also a way to ensure credibility according to Shenton (2004). Triangulation refers to the use of multiple methods to ensure that the results match reality more closely. This has been used as data has been collected in different ways, such as literature review, multiple interviews and to some extent with a focus group and case study focusing on one company.

According to Shenton (2004), transferability signifies how well the findings of a study can be applied to other situations, for example to a larger population. This can be challenging for qualitative studies when observations have been made in the specific contexts in which they occur. Transferability can be facilitated by providing clear descriptions of the conditions and choices made that underpin the study. According to Shenton (2004), information that can be useful to readers includes the period during which the study was conducted, the organizations involved, how the data was collected and the geographical extent of the study. All these factors have been described in one way or another in the methodology. Although the study was largely based on the specific work area of one company, the results have been generalized to the extent that they are applicable in other parts of Sweden.

According to Shenton (2004), the third perspective, dependability, can be achieved by the authors describing in good detail the process of the work. From this, future studies can be conducted in a similar way by other researchers and achieve similar or different results. The importance of the auditors following the progress of the thesis is also stressed, so that they can assess whether the correct research procedures have been applied. The reliability of the detailed data in this thesis has been affected by the ethical considerations made to respect the company studied and the personal integrity of the interviewees, and information that could be considered sensitive has been excluded from the study. The interview guide is presented at the end of the report, which can facilitate future, similar, studies. During the course of the thesis, the work was reviewed by supervisors who noted or critically reviewed the work processes and provided feedback. A peer review was also carried out by colleagues from the same master class.

Finally, Shelton (2004) presents confirmability as an important factor for credibility, where human perception and beliefs should be limited so that the work is not shaped towards the biased. However, ensuring full objectivity could be difficult, for example because the interview guide for the interviews were created by the authors. From a broader perspective, the thesis started with limited knowledge of the subject, and previous research has largely formed the basis for the choice of work processes. This may to some extent ensure the objectivity of the thesis.

4 Interview study

This chapter presents the results of the 10 interviews conducted with industry-related stakeholders with the aim of answering the study's research questions and other uncertainties discovered from the literature review. The results are presented according to the major questions that the interviews sought to answer to; what are the opportunities and difficulties of reusing windows, who will lead the change, what business structure change is needed and how will prefabrication be affected by implementing reused windows? A generalised interview guide of what questions were asked during the interviews can be found in the Appendix.

4.1 What are the opportunities and difficulties of reusing windows?

What will the future possibilities of reusing windows be and what are the difficulties and bottlenecks that need to be addressed? In this subchapter the above-mentioned factors are presented in more detail, and in Table 5 one can see the summarized opportunities and difficulties gathered from the interview study.

Table 5. Opportunities and difficulties of reusing windows

Opportunities
Climate saving potential
Cost saving potential due to rising prices of new raw material
Gives room for new innovative solutions
There are other potential areas of use if requirements and quality are not met
Difficulties
Finding extensive quantity
Limited lifespan and weakened building physicals
Significant early inventory and purchase
Cost of refurbishment will lower the will of using reused windows compared to new ones
Probably large quota 2-glazed windows installed in older buildings that does not meet requirements

Most interviewees see positive aspects of being able to reuse windows from an environmental perspective as well as in view of already observed economic trends such as increasing prices of raw materials. Nevertheless, they also mention the complexity of the component as a major obstacle. Compared to other products that the respondents see reuse potential in, for instance Contractor A and B and the Client give examples of structural components and various installation technology products, a limited lifespan and, over time, weakened building physical characteristics make windows a more technically complex component to reuse.

Another issue mentioned by all interviewees as perhaps the biggest problem with using reused windows in larger complex projects is finding such extensive quantity of the same dimensions and construction, while achieving structural requirements such as U-value and airtightness.

Supply and demand are something that is currently not being met according to most stakeholders, and will affect all steps in the supply chain, and perhaps mainly the architects who often today search for compatible products. Architect B, Client, Senior Window Adviser and Reuse Centre Manager highlights that the inventory must be done early to determine the quantity, which is then the responsibility of a company specialised for the purpose. Or, as Architect B suggests, can be the responsibility of architects. If the right quantity is found and purchased, there is a further issue of inventory. Compared to ordering newly produced windows from a window supplier, which can be largely delivered just before the start of the project/installation, the early purchase is likely to result in the products needing to be stocked for a longer period of time. According to the above-mentioned stakeholders, this may affect the motivation of various companies to buy remanufactured windows, because it will be a cumbersome and costly process versus ordering new products.

The Senior Window Advisor together with Architect B pointed out that windows taken from an older building will require some restoration work, and that someone else should perform that. This could be a solution to windows achieving an arbitrary quality, but the above-mentioned stakeholders together with the Reuse Centre Manager and Contractor A believe it will be a matter of cost, where today's relatively cheap prices of windows will not favour the competitiveness of reused windows.

As a result of the rapidly accelerating energy requirements placed on buildings over the past two to three decades, windows installed today are significantly more energy efficient versus windows installed just 20-30 years ago, the Senior Window Advisor mentioned. At that time, mostly 2-glazed windows were installed and today, in most cases, 3-glazed, 2+1 glazed or even 4-glazed windows are required. The Senior Window Advisor along with both the Client, Contractor A and B pointed out these high energy requirements as a bottleneck for implementation of reused windows in the near future. This is due to the problem that the buildings that will be dismantled in the next few years will probably only have 2-glazed windows installed which do not meet today's energy requirements. In these cases, the above-mentioned stakeholders only saw the possibility of reusing parts of the window components at present, i.e., reusing either the frame and the window casings separately, in the same function or new, or alternatively that they can be used in complementary buildings that do not require the same type of thermal requirements.

Architect B presented another solution, already used in a well-known award-winning Danish project[1], where two aesthetically different 2-glazed windows were fixed together and became 4-glazed, thus meeting the requirements better, see Figure 5. Architect B explained that the windows were architecturally peculiar for this project, as the design differed significantly (Ledanger , n.d.) compared to "normal" windows. However, Architect B felt that in the future this creative approach could be a desirable solution to meet upcoming requirements regarding the use of available resources.

[1] Upcycle Studios- Townhouses made of reused windows, recycled concrete and discarded flooring boards, saving up to 45% CO_2 and 1,000 tonnes of waste was turned into building materials. (Ledanger , n.d.)

Figure 5. Multiple double-glazed windows assembled together (Ledanger , n.d.)

Nevertheless, the Senior Window Advisor found it difficult to see how the requirements around U-values could become significantly stricter, as they are already so low. According to the Senior Window Adviser, this would signify a higher potential for reusing windows produced today in the future. Craftsmen A and B also mentioned the advantages and opportunities that today's windows will bring for reuse compared to older windows. From their perspective, they felt that today's fasteners, which are much more flexible and easier to install, may signify that windows will be easier to dismantle and reduce the risk of damage to the components. This was also backed up by the Platform Owner who is working on developing construction methods for Derome.

Aluminium clad or wood-aluminium windows were considered, according to the Senior Window Advisor, to be the type of window that has the most potential to be reused because there is no lack of functionality when this type is taken down at the end of its lifetime. This due to aluminium being relatively easily maintained and insensitive material to various external factors, which would otherwise bring wear and tear to wood-framed windows. An important aspect according to the Senior Window Advisor is the knowledge of what the intended windows to be reused contain or are coated with. This can give an idea of how old the window is and therefore approximate remaining life. The respondent also stressed that it is highly impractical to install a window that only has 5-10 years left, but that ongoing maintenance can play a major role in giving windows a longer life.

4.2 Who will lead the change?

Several of the actors interviewed, Contractor A, Architect B and Architect A mentioned that the client is an actor that needs to take great responsibility for the implementation of reuse to become a large-scale market. Architect B and Contractor A see their work as faithful to the project descriptions and requirements set by the client and must work within that framework. These actors point out that if there are no requirements for reuse in tenders etc., it is difficult to justify reuse from a cost-time perspective. Even if clients were to require reuse in procurement, it necessarily does not mean that it is a possibility. Contractor A suggests that there have been projects where the client have set these requirements, but have not been aware if it is possible, i.e., if there is a supply of the required components or materials. The client therefore needs to be aware of what the market looks like before setting the requirements for the project.

Architect B also perceives an interest in increased reuse from clients, but this interest is hindered by uncertainty regarding cost and warranty issues as well as general ignorance. According to the respondent, in many cases various clients wish to see functioning pilot projects prior to their own commitments. Pilot projects were also highlighted by Contractor A as a possible key to getting working processes for reuse. The Client has previously been involved in the inventory of an existing building that was planned to be demolished. A full team of architects, clients and contractors were involved and were able to contribute with their knowledge. However, the Client felt that the process itself would be much more efficient if there were templates and recommendations that they could follow at the time. If this were the case, the warranty issue, which was the responsibility of the contractor, would not be as flawed. The warranty issue on reused components, and windows, is something that the vast majority of stakeholders interviewed expressed concerns about.

It is also easy to say that the client is responsible, partly because they set the requirements, but it too depends very much on who the client is. In the case of Derome, the client is in many cases a private individual who is buying a property or home. In these cases, it is the private individuals who make the requirements, even though Derome acts as a "first appointed client". According to the Client, there is no clear indication that the end customer will demand reuse in their investments, but this may be because the benefits are not sufficiently clear. Both the Client and Contractor B believe that in the future, through the already existing and accelerating sustainability trend, more customers will be intrigued by living in more sustainable housings made by reused materials and components. Architect A, on the other hand, does not believe that reuse will be difficult to sell to these customers due to the clear environmental benefits, which more and more people in society are showing greater interest in.

For Derome's multifamily production, and companies with similar business lines, customers are largely private individuals investing in new housing, who may be the most influential actors according to the Client. Today, customers do not require reuse, and may not even accept it in their new investment. This results in barriers for clients and other actors in the sector to implement reuse in projects. Again, this perspective was highlighted by Contractor A in their interview. The interviewee felt that private individuals, in their word's "taxpayers", must also put their demands on the actions politicians and municipalities take with their money, suggesting that there is an authority for change.

Although the client was seen as a driving force by many respondents, the Client, Contractor A, the Recycling Centre Manager and the Senior Window Advisor considered more flexible building permits are needed from the municipalities to enable the client to set requirements for reuse in tenders and project descriptions. As planning permission currently needs to be submitted at such an early stage of the project, it prevents changes later on. Today, very specific descriptions of the windows to be used are required such as intended size and location. The limited supply and the likely long inventory time required to find reusable windows, prevents the client with partners from being able to guarantee a precise window component so early. Furthermore, the Client suggests that building permits must be able to tolerate, for example, a limited size range of windows for the intended project, which would then facilitate and extend the search for suitable window components.

Architect A, the Client, Contractor A, Contractor B, the Designer, and the Reuse Centre Manager, all highlighted that there is a lack of someone in the value chain to enable the reuse of windows. They did not consider that they themselves are responsible for the actual inventory, disposal or refurbishment of the components, but that a new actor in the construction sector is needed to facilitate these steps. According to the Senior Window Advisor and Contractor A, similar roles exist today but that it is only on a small scale, and not applicable to the whole market. This actor would carry out inventories of existing building stock, find suitable windows (including other materials and components), purchase these and be the intermediary that conveys the soon-to-be available supply to its network of customers. According to the Client this actor would also contribute to a wider dissemination of knowledge in the sector and invest in reuse for when economic initiatives increase. Alternatively, this operator would also refurbish the dismantled windows so that they are in a customary and acceptable condition. The establishment of such an operator would require good cooperation with dismantling companies.

The Reuse Centre Manager and Contractor B both mentioned that construction companies need to take more responsibility of using their own residual products. They suggest that where a project has been carried out, there is often waste in the form of brand new, functional products that end up at reuse centres due to ignorance or strict policies. The Reuse Centre Manager expressed that contractors could provide their own storage facilities just for these occasions, storing leftover material and trying to use it themselves in future projects.

Finally, most interviewees believe that the implementation will depend on the sector, it will not be one actor that takes it on even though interviewees felt that some actors have more responsibility to drive the issue forward than others. As the majority of interviewees see an increasing interest in reuse in general, it is considered important that companies work towards this development. It requires good communication and cooperation with all parties in the value chain, as well as the various actors in society.

4.3 What business structure changes is needed?

As mentioned in Chapter 4.2 above, several of the actors interviewed felt that there is a lack of a player in the market who is responsible for various preparations and mediating the supply to stakeholders. The Client suggested that this is a role that Derome, or companies with a similar business structure, can develop internally. For example, construction companies that already have a builders' merchant within the group can develop its business model to supply secondary materials and components and obtain the sales. On the company's behalf, this would facilitate the design process, as the supply is secured and the issue of long stockkeeping in the prefabrication factory is no longer a concern, while it would be a more economically and environmentally sustainable business. The Client pointed out that this type of business development would probably not be profit-driven at first, but the more the requirements are strengthened, the economic initiatives will follow.

As mentioned earlier, Contractor A and Architect B, among others, felt that there needs to be good examples of how projects with reused windows should be carried out, in order to get a momentum in the market and so that more stakeholders dare to invest in the development. Both the Client and Contractor B believe that the studied company is at the forefront of sustainable development and has committed to more environmentally positive innovations than today's requirements demand. However, if peripheral and crucial reuse systems were already in place, the studied company, and other similar companies, would likely have worked with higher percentages of reused materials and components. The Designer also felt that no major changes needed to occur in the studied companies business model for greater implementation of reused windows, but believed that economic and regulatory initiatives, specifically around material shortages of aluminum and other materials, would accelerate a change.

The design phase was noted by most of the interviewees, including the Client and Contractor B. They expressed that when the design is to be implemented for a project, early knowledge of the windows to be used is required, but for the inventory of suitable reusable windows, a design is required to narrow the search. This will lead to a costly and time-consuming process, as the design will probably need to be changed during the project. Also, the Senior Window Advisor mentioned that disassembly is a time-consuming and complicated construction phase where older fixtures may be encountered. For increased circular construction, the Senior Window Advisor and Architect B expressed that if the building had been designed to facilitate later disassembly, a greater quantity of unaffected windows could be extracted. The concept is called Design for Disassembly.

4.4 How will prefabrication be affected by implementing reused windows?

Regarding prefabrication, also referred to as off-site construction, most interviewees believed that the imminent difficulties did not lie in the installation and production itself. The challenges lie in much earlier stages such as finding the right quantity and quality of windows, logistical solutions such as warehousing and delivery, and warranty issues. What was highlighted during the interviews is how standardised off-site construction is and thus particularly susceptible to ambiguities, uncertainties about deliveries, among other things, and how the installation of reused windows should take place. The Client and Platform Owner expressed that it is likely to be more complicated to implement reused windows in prefabrication compared to on-site built building complexes. Prefabricated building volumes are much more sensitive to change, and the interviewees expressed concern that unpredictable problems cannot be solved in the same way. On the other hand, the Designer does not believe that there are that many differences when it comes to reuse windows when using prefabrication compared to on-site construction. According to the Designer the main difference is safety since the installation will not be done at high altitudes as well as the factories contributes with a lot of helpful machinery when it comes to installing.

The Platform Owner and the Client pointed out that the windows to be installed had to meet certain size- and fixing requirements to fit into the standardised models. If these requirements are not met, reprogramming of the files will be required, which is a time-consuming process, and therefore also an economic factor. Greater flexibility for changes is needed here, so that the control files sent to the factory machines match the intended windows or vice versa.

Craftsmen A and B, who are involved in installing windows, suggest that if they are aware of how a specific window is to be installed and that it is in the right place at the right time, the potential for reuse is high. The craftsmen would rather not see any kind of impact on their already time-optimised process, for if they were to receive inadequate information, it could probably cause delays in the entire flow of the manufacturing. From their perspective, the greatest responsibility lies with those in the “office”, in other words those who design the prefabricated modules.

5 Discussion and conclusion

In this chapter the results from the theoretical framework and the interview study will be further analysed, compared, and discussed. The aim of the discussion is that the integrated analysis of the theory and interview study will lead to a conclusion that answers the research question and aim of the report. Furthermore, the methods used to write this master's thesis and how the work could have been improved to lead to more in-depth research on the topic are discussed.

5.1 Reusability of windows

During the interviews, all respondents mentioned that one of the main concerns regarding the reuse of windows is the difficulty in finding the right models and sizes in the desired quantity. This is a persistent problem whether working with prefabrication or on-site construction. The quantity of windows becomes a problem, especially when focusing on multi-family buildings, but on the other hand the potential is higher when building for instance villas. Although the possibilities of using reused windows are greater in the construction of villas, companies building larger, more complex buildings still need to dare to take a step in that direction and think outside their usual business strategy. The use of reused materials requires some rethinking within the industry, where innovation is an important factor. As Architect B mentioned in the interview, there have been projects, partly in Denmark but also in Sweden, where the reused window is not used in their original form, which could be a potential solution if the right quantity of windows with acceptable thermal conditions cannot be found. Then windows with lower thermal conditions can be assembled together to reach the right requirements. Those pilot project that shows a high degree of innovation is something that companies working with these types of activities should take into consideration when implementing reused windows. The roles that are currently doing the design will need to be more open to coming up with creative solutions with what is on the market at the time when the windows must be found. Since this can be difficult there may need to be an acceptance of different solutions at the beginning.

In the theoretical framework, SP fönster (n.d) mentions that 2-glazed or 3-glazed windows would function well as they have good thermal insulation, which imply that they maintain low energy consumption. However, in the interview study, the Senior Window Advisor mentioned that due to the increased demands on energy consumption, it is unlikely that today's 2-glazed windows will be able to be reused to a greater extent in multi-family buildings. Instead, the Senior Window Advisor suggests that it is required to be either 3-glazed, 2+1-glazed or even 4-glazed. This can be linked to the above-mentioned need for new innovative solutions, such as the Danish project where several 2-glazed windows were put together and thus met the requirements. If creative solutions like this were to be applied in more projects, more of the future supply of 2-glazed would be used and the amount of waste reduced. However, this is something that will be difficult to implement in the standardised process of prefabrication. The reason is that it would likely involve time-consuming preparation and increased lead time at the window station would because an additional step would be added during installation. This would also affect the whole production to the less efficient. That is, unless the actual assembly of multiple double-glazed windows takes place separately from the factory in advance.

The Senior Window Advisor emphasizes that windows with either aluminum or wood-aluminum frame have the greatest reuse potential which confirms what was emphasized by Davidsson et al. (2002) and Khan et al. (2019) in the theoretical framework. The explanation given by these authors and the Senior Window Advisor is that the material does not require as much maintenance and it is less affected by the weather conditions that windows are exposed to during its lifetime. In the theoretical framework, Davidsson et al. (2002) and Khan et al.

2019) also mentiones that the production of aluminum is a climate-impacting process. However, it may be worth disregarding these factors as the lifetime of aluminium-framed windows will be significantly longer if they are reused for as long as possible compared to PVC and wood. When the entire window components can no longer be used, new innovative solutions can be found, as mentioned above, to continue using certain parts of the window. This can be considered to compensate to some extent for the climate impact of the aluminium production.

5.2 Stakeholders/actors role in the implementation

Andersson et al. (2020), Andersson et al. (2021b) and Sormunen & Kärki (2019) all presented that the lack of knowledge about reuse can lead to poor attitude towards this very issue. From the interviews it could be interpreted that all stakeholders saw a value in reuse, mostly from an environmental perspective, and had an interest in increasing it in the sector. This suggests that they have a positive attitude towards reuse and that, from their point of view, it is not the attitude that is a barrier. There is a clear knowledge among stakeholders that reuse is good, but the lack of knowledge lies more in how to implement it and what the effects will be. Andersson et al (2021b) also mentioned that it is of great importance that the whole sector has a positive attitude to facilitate the implementation and achieve various goals. In addition, from the interviews it can be suggested that the stakeholders are positive even though there are some divided opinions about the approach and the success of window reuse. In order to increase the knowledge on the subject and thereby increase the willingness to reuse more, greater collaboration is needed. The results from the interview study shows that it is not only within companies that collaboration and knowledge sharing needs to increase, but rather within the whole industry. Thereby, the collaboration should take place between value chains, sectors, and roles such as policy makers, the public sector etc.

According to Andersson et al. (2020), ignorance among stakeholders is one reason for the problems surrounding the current undeveloped market for reuse and the difficulties in finding an arbitrary quantity of good quality components to meet demand. There is not a wide range of actors taking on the responsibility for quality assurance and inventory although according to Andersson et al (2020) there has been a trend in recent years that the number of actors in the market has increased which in turn may increase knowledge in the sector. This can be linked to the new actor, which Architect A, the Client, Contractor A, Contractor B, the Designer, and the Reuse Centre Manager suggested as an enabler for reuse, and the Client also expressed that this would be a role that the researched company had been able to implement in their business structure. However, who will take on this role is debatable, but it must be someone who is willing to be challenged within the industry and who can come up with new innovative solutions. Above all, there must be a strong interest in reuse. As the studied company has shown a great interest, it could be considered that they themselves could take this responsibility. In the theoretical framework it was mentioned by Gorgolewski (2008) that the new role could be some sort of management contractor which according to the author often have a great willingness to make necessary changes within the business, in comparison to an ordinary contractor where there is more resistance. Another value created by reuse and the need for a new actor is social sustainability. Since there is a need for a new entrant in the sector, new labor is created, in other words there is an employment value.

If the above-mentioned new actor where implemented, the company in question could have been an early adopter, which could have positive effects but also barriers to overcome. According to Almasi et al. (2020), Kärki and Sormunen (2019), Andersson et al. (2020) and the Client as well as Contractor A, it is said to not be economically driving at the beginning due to time consuming and untested processes. However, according to the Client, it is only a matter of time before it becomes well established once economic initiatives follow and the price of raw materials increases as a result of new restrictions. Suggestively, this business venture could have given the company a good reputation as well as showcasing its excellence and spreading knowledge to the rest of the sector as confirmed by Andersson et al. (2020).

From the perspective of the surveyed company, private individuals in the form of tenants or home buyers are considered the final customer, which is a high impact actor. This has been noted by various respondents but also many of the literature study's included reports such as Andersson et al. (2021a), Balador et al. (2019), Ferrando et al. (2012) and Gorgolewski (2008). Like many of the other actors, the client does not have full knowledge of reuse, but what Gorgolewski and Andersson partly stated was that if there is a willingness on the part of the client to implement reused components, knowledge will subsequently increase. The client did not believe that there was a willingness on the part of Derome's end customers today and saw this as a barrier. So, in this case it suggests a dilemma. But something that Architect B mentioned was that for the willingness to increase on the part of the client, there may have to be some motivating "fuel" in addition to the environmental benefits. Even though architects are considered to be an important stakeholder when designing with reused components, Architect B believed that the client should include reuse as a requirement in the tender and project requirements, since they cannot make this decision on their own. However, the Client believes that if the main customers do not want to invest large amounts of money on something that is not new, and then a motivating fuel could be a cost reduction, but then you also face the problem that reuse is not yet economically driving.

Many of the stakeholders identified in Chapter 2.4 have mentioned the client as a driving force for the move towards more reuse in the sector, which is partly confirmed by the interviews. The client seems to need to take on a greater role in implementation, but it can be argued that this is not only the client's responsibility. As mentioned in the interview study, the Client, the Senior Window Advisor, Contractor A and the Reuse Centre Manager felt that clients need to be given more flexibility in planning permission from the Building Control Committee for reused windows to become a possibility. This could be argued to be one of the policy incentives needed. According to Balador et al. (2019), Høibye & Sand (2018) and The Ellen MacArthur Foundation (2017), incentives would also be needed regarding requirements for reuse to be used to a certain degree, this from municipalities or similar, for the construction sector to actually find motivation to use reuse. At the same time, the authors mentioned above argue that policy is highly influenced by what stakeholders in the construction sector want. There is no clear stakeholder to be responsible, but discussions and negotiations will be needed between several actors, including the client, in this case the company under investigation, along with the Building Board and other political leaders. According to Andersson et al. (2021a) and Balador et al. (2019) the construction sector lacks working methods for the involved actors regarding scaling up reuse as well as lack in collaboration within the value chain, which signifies that the potential for development remains small. Linked to the above-mentioned regulations and requirements on reuse, this may be necessary to force companies to actually reuse more, which require some stakeholders to take on the responsibility. However, it is debatable whether this should be a constraint, but it may be considered necessary to achieve future environmental objectives.

5.3 How will the process of prefabrication be affected?

As mentioned, in Chapter 2.5, some of the barriers associated with prefabrication are due to its complexity, logistical challenges, cost and design (Eltoukhy et al., 2021; Hewage & Kamali, 2016; Dong et al., 2020). When comparing those barriers with the ones mentioned during the interviews, the result is similar. However, the interviewees did not consider reusing windows linked to the prefabrication process as a barrier per se, but rather the problem of finding the right type of window models in the quantity needed. As mentioned by all the interviewees the windows must be found at an early stage during the planning phase which can be years before they can be installed in the factory which creates a need for warehousing. In conclusion, the interviews stressed more that the barriers arise largely not because of prefabrication as a method but rather because of a combination of factors that occur earlier in the value chain. Part of the solution to the problem of reuse is better communication where the different stakeholders must discuss solutions together to overcome the barriers mentioned in this section. However, one factor that can have an impact is the time aspect. As Doran and Giannakis (2011), Eltoukhy et al. (2021) and Jian et al. (2020) mentions in the theoretical framework, prefabrication is a time-effective process which is also mentioned by Craftsmen A and B. When implementing reused components in the prefabrication factories it must be taken into account that the process may take longer. The Client and Platform Owner stressed the change sensibility of prefabrication and the risks of delays as there will be greater risks that changes will have to be made during the production of modules. Due to problems regarding finding a higher number of windows, the time before the production can start will most likely be affected the most.

Furthermore, when comparing the possibilities of implementing reused windows in on-site construction and prefabrication, the answer differs between the interviewees. As mentioned earlier in Chapter 4.4, the Client and the Platform Owner believed that reuse is more difficult when it comes to prefabrication, mainly because it is so standardized and since there is more opportunities to come up with innovative solutions when performing on-site projects. The Designer, however, did not think there would be any major differences in terms of on-site vs. off-site but rather saw opportunities regarding risk issues when it comes to off-site construction. The reason why the respondents' answers differ may be due to their different familiarity with the prefabrication processes, where the designer did not have the same relation to this type of construction process. Another aspect to consider is also their experiences with working both on-site and off-site as well as years of experience in the industry working in the respective ways.

It can be argued that the implementation of reused windows in prefabrication will need a learning period. As one can read in the theoretical framework, Hewage and Kamali (2016) mentioned that prefabrication is a standardized method. This was also confirmed during the field study where one could observe that the work carried out by the craftsmen had to be executed within a certain time frame in order not to create obstacles for the other processes. Moreover, Craftsmen A and B also stressed the difficulties with prefabrication being such standardized method and considered that those who will be affected, and thus have to take a great responsibility, are those who create the design with the associated control files which the machines in the factory then follow. Although the actual work involved in getting the process up and running is largely dependent on the stages prior to installation in the factory, craftsmen, especially those involved in window installation, must be prepared for future changes. The supply of reused windows has an uncertainty, that does not exist in the use of newly produced windows, which can lead to differences in models and window sizes. This could affect the working process in the factory if there is a lack of knowledge about the windows to be used. Additionally, this could potentially affect the otherwise effective lead times in the factory. For instance, Craftsmen A and B mentioned that a special type of fasteners is currently used when installing windows in the factory. If reused windows were used instead, this type of fasteners may have to be changed and/or the type of fasteners will to a greater extent vary from project to project. This is something that craftsmen must be prepared for.

During the interviews with Architect B and Contractor A both said that there must be a reason, e.g., requirements, for justifying reusing components from a cost-time perspective. In the theoretical framework it is mentioned by Hofmann et al. (2017) that since a change towards circular business requires changes on the organizational level the focus lays on redesigning and restructuring the product-service-system and not on making profits. A change towards circular business could thereby be considered as one reason for justifying stepping away from the perspective of costs and time.

However, if reusing windows are to be implemented in prefabrication, additional costs are inevitable at first. As mentioned above, the workers in the factories may have to be further educated as they are to some extent moving away from the current very standardised way of working. The Client also mentioned during the interview that although it is costly at the beginning, the rules will probably change in the future where it might be required to use reused materials to a certain extent to meet the environmental requirements. Thus, as a company, it may be a good idea to be ahead of the curve and start planning now for how these changes will occur. In terms of the costs, several authors in the theoretical framework mentions that it is more cost effective to work with prefabrication compared to on-site construction (Doran & Giannakis, 2011; Dong et al., 2020; Hewage & Kamali, 2016; Li et al., 2014; Jian et al., 2020; Molavi & Barral, 2016). Making the necessary changes required in the factories will take time, but the Reuse Centre Manager and Contractor A both mentioned that it will be costly changes even though it can be considered that implementing reuse within prefabrication in particular is something worth investing in. Partly because of the advantages mentioned in the theoretical framework regarding prefabrication, such as higher quality of the final product, more sustainable, and faster construction times. These advantages in combination with being ahead when it comes to reusing will but he company in the forefront on the market.

Prefabrication is already a relatively low-waste construction process, as, according to Hewage and Kamali (2016), it reduces waste generated on site versus site-built structures. But to make it a more circular business, solutions are needed to facilitate reuse. DfD has been recurrent in the theoretical framework by several authors (Ferrando et al., 2012; Almasi et al., 2020; Kärki & Sormunen, 2019; Andersson et al., 2020) as well as in the interview study as a solution to dismantling difficulties and for extracting larger quantities of windows. In the future, if comprehensive DfD is applied to prefabrication, it could mean that studied companies have better documentation on structural features of already installed windows and that more windows could be extracted. Good documentation and dismantling regulations would also support what Craftsmen A and B and the Senior Window Advisor highlighted about current fixings, which would already facilitate the dismantling of windows. The technology used in prefabrication is advanced and it could be seen in the factory during the field study that the use of prefabrication contributes to waste reduction. However, what may need to be reviewed in terms of technology is that there is potential for improvements in terms of making the process less sensitive to change, which would facilitate the implementation or reused windows.

5.4 Business strategy proposals

For this company, and similar companies, where the production of multi-family houses is the business, the end customer is usually private individuals. It has previously been noted from the interviews that there is currently no major commitment from private individuals that reused materials will be applied in their future homes, which may be one of the reasons why the impetus for implementation is not reaching its full potential. An important commitment for these companies is to present good reasons why reuse should be used and what benefits it can bring to customers, which may create awareness among them. As mentioned earlier, ignorance is one reason why motivation is low. Further, this can also be linked to political incentives where decisions on reuse can be made if the drive and behavior from the public is positive for implementation (Wilson, 2007; Balador et al., 2019).

A likely outcome of introducing reuse may be that end-customers want some form of compensation for the use of older components in their otherwise newly built investment. It may be that they want to see cost reductions. The issue of financial benefits to the end customer may well be an issue that needs to be addressed in some way. Currently, as mentioned earlier, there are unresolved issues of quality assurance which may be one of the reasons for the above-mentioned barrier.

What can be concluded from this study is that it will be challenging to find a significant quantity of windows of the same size for large scale projects. This may lead to an impact on the roles currently responsible for design. These roles will need to be more open to finding creative solutions based on what is available in the market during the design phase. This implementation may be perceived as unattractive to architects and designers because it may hinder their creativity. What Andersson et al. (2021a) pointed out was that architects probably need to change their habits and attitudes towards what is considered attractive in buildings. From the interviews with Architects A and B and the Designer, their attitude towards reused windows was perceived as positive. It is debatable whether this is because they are not aware of what the implementation may mean for their work in general. Or if it is actually as Ferrando, et al (2012) expresses that architects are often seen as trustworthy actors regarding environmental issues and actually see the tangible benefits outweighing the obstacles. Furthermore, in the interview, Architect B believed that the responsibility of finding the windows needed could lie on the architects. However, as they must be found in the early stages there might be some other role that is more suitable for this specific task. According to Gorgolewski (2008) the client would be most convenient for this. A business proposal to the studied company, could be to develop its building materials trade with secondary materials as well. If this were to happen, it would simplify the difficulties of finding sellers or reused components, but the problem of having access to such large quantities as needed is likely to remain.

In addition, at the beginning of the implementation, there may need to be an acceptance of deviating solutions from what is considered their current approach. Similar to what Hofmann et al., (2017) exemplifies about organizational risk levels, it may be necessary for companies to dare to take these risks despite uncertainties. By restructuring towards circular business models, it may be possible to secure its future in a more competitive recycling market (Hofmann et al., 2017). It is debatable how widespread these observations may be, which is likely to depend on how early companies introduce reusable windows to their processes. If a company chooses to be early in a development such as this, it is likely to encounter unforeseen obstacles along the way, which may have a greater impact on the various phases of the project. However, if the company in question implements reused windows when it is well known in the sector, there would most likely be more well worked out strategies.

Other aspects that have not been highlighted but are of utmost value include the social impact of this whole conversion. Based on the results, comparisons and discussions, there are a number of factors that could have an impact on society. If reuse, of windows but also in general, were to expand in the market, it would probably mean a lot of new job opportunities in the construction sector. There will be new types of services, such as quality control of products, coordination of business between different companies, more dismantling companies, etc.

5.5 Discussion of methods

The methods used during this master thesis has generally worked well were the main obstacle being the time limit. There was a desire to conduct more interviews with stakeholders who have the same professional role, but due to time constraints, one interview per stakeholder was prioritized. Conducting multiple interviews with individuals with the same role would provide a more generalized and concrete result. More angles and comparisons along with a deeper analysis of the personal experiences and how these differ, for example depending on the number of active years in the sector etc. At the beginning of this thesis, strict restrictions were applied as a result of the corona pandemic. This meant that many professionals worked from home, this together with the distance between Varberg and Gothenburg, was the reason why the majority of the interviews were conducted via Microsoft Teams. Although the interview questions tried to be kept relatively similar during all interviews to minimize the risk of questions being biased etc., it can be considered that there would have been a more natural discussion if the interviews had taken place in a face-to-face meeting. This partly because the conversation falls more naturally, making it easier to ask follow-up questions.

Another issue that occurred during the work were that reusing windows to the extent that they will achieve their exact former function is something that does not seem to have been explored to any great extent. Finding reliable references on the subject was challenging, and much of what was found was only directed at single villas and/or complementary houses. The end result was thus partly biased against what the interviewed stakeholders told us during their interviews. The lack of previous research on the subject may possibly support what the study has highlighted – that windows are a significantly complex component to reuse.

The *snowball effect* used to set up further interviews worked well for the most part. However, this meant that new actors were suggested to be interviewed by respondents late in the process. The suggested stakeholders were considered to be of relatively high importance according to some respondents, but due to time constraints, the opportunity to interview these stakeholders was removed from the study. In addition, it is likely that there are more actors on a smaller scale who will be involved in this transformation towards reuse. An active choice to focus on the main, larger actors was made at an early stage of the study. It is debatable how much impact the responses from potential stakeholders would have had on the study.

Another idea that was also not included in the study due to lack of time is the role of the users, in other words those who are in the housing market or are going to buy a future home and the end customer/client in the perspective of Derome. This had reinforced the fact that some of the stakeholders interviewed considered that private individuals are customers who have a great deal of influence and need to be considered, especially when a company is building housing. This would have provided an interesting perspective on whether their interest in buying a home would have increased or decreased if it was built with reused windows.

5.6 Conclusion

One conclusion that can be drawn from this thesis is that the windows that are currently installed in older buildings will be difficult to reuse. This is partly because it is difficult to do proper quality assurance as there is no documentation of maintenance and it is therefore difficult to estimate how long they will last. As there are regulations on certain U-values, this is further complicated by the fact that these regulations have become stricter since the older windows were installed, meaning that today's dismantled windows will not meet the requirements. In all likelihood, significant parts of the window stock have been installed without the intention of reusing them later, making it difficult to dismantle them without breaking them. A conclusion based on this is that reusing windows from demolished properties will be challenging in the coming years. However, with some uncertainty as to when this might be feasible, when today's windows, with still relatively high U-values and of better quality, are ready for dismantling the challenges might have decreased.

To answer the first question under investigation, *'What stakeholders are needed to successfully implement reuse of window components?'* one can say that to a certain degree all of the stakeholders must contribute. However, it is clear that there is a lack of a necessary actor to solve the barriers that need to be overcome in order to fully enable the reuse of windows. According to the theoretical framework and the interview study, it can be considered that the client has to be one of the actors who takes more responsibility. This is due to the perceived lack of an attitude to dare to reuse and risk the extra costs that may arise. The conclusion is that if there had been more pilot projects, it would have been less complicated for the customer to accept reuse. This is because there is a lack of willingness to be first, although those who dare to be so will be at the forefront in terms of both reuse and sustainability. Municipalities also need to take more responsibility to some extent to contribute to these changes by relaxing building permit requirements, as was mentioned in the interviews, see Chapter 4.2. This to make it easier to overcome the problems of finding the right windows in larger quantities and to allow for new aesthetic innovations.

Something that has been recurrent throughout the study is the constant rhetoric about who should shoulder the main responsibility for this implementation and reform. The various stakeholders constantly argue that it is someone other than themselves who should take this role, for example much of the findings suggest that the client should be the driver, but at the same time they argue that changes in regulations and relaxation of building permits are required. This leads to stagnation and stakeholders just passing on the responsibility role to another stakeholder they believe should take more responsibility. What is also noted is that being at the forefront of reform and development is a major risk, as there are clear knowledge gaps and a clear leadership role. This leads many to act reactively and with caution, when what is really needed is action and clear stances. Although the likely future new regulations around reuse may be a motivation, something further is needed to counterbalance the clear lack of knowledge transfer and leadership. Good leadership is needed to achieve the goals of transitions such as these and also new actors introducing new solutions that create motivation in the sector.

5.6.1 Business strategical proposals

To address the second research question' *What business strategy changes are required for these types of construction companies to reuse window components in their industrial construction projects?'*, proposals are presented on the initiatives required from the operators as well as proposals for internal business changes in Table 6 and Table 7 below.

Table 6. Proposal of changes and/or initiatives for the involved actors/stakeholder

Actors/stakeholders	Potential for improvement
Client	Must be a driving force in order to implements reused windows
	When possible, the client should require that reused windows are used in projects
	Stay educated regarding the subject and share their knowledge with others involved in the projects
Architect and Designer	The architects and designers should see the opportunities of being more creative and innovative when designing with reused windows.
	Be aware of the market and help finding the reused windows needed
	Design for Disassembly
Others	All involved actors/stakeholders must have a positive attitude towards reusing and be prepared for necessary changes within the organisation
	Everyone must increase their communication in order to prevent misunderstandings
Politics and Society	Loosen the requirements for building permits
	Educate the society of the possibilities of sustainable actions, in this case reuse
Reuse Consultants	Expand the market of reused windows
	Collaborate with different reuse centres and create for instance a website to make it easier to know the current supply
Dismantling	Dismantling in a way that does not harm any components

As seen in Table 6 above all actors/stakeholders must be a part of the implementation to some extend and be prepared to contribute to necessary changes. However, as seen the main responsibility lays on the client who has the biggest influence on the project execution. What can be concluded is that there is probably also a need for a new actor in the industry responsible for finding, refurbish and quality assess components etc. The companies must also do internal businesses -and operational changes. Proposals for these can be seen below in Table 7.

Table 7. Proposals for changes and/or initiatives on a business level

Internal business initiatives	Companies could develop their business areas, such as builders' merchants, to include secondary materials and components. This solution could accommodate some of the responsibilities that would otherwise be provided by the proposed new entrant. Instead, it is kept inhouse.
	Take inspiration from previous successful pilot projects and/or be at the forefront and build their own pilot projects
	Educate and motivate employees about reuse and its benefits, as well as the difficulties that may be encountered
Prefabrication	The method should be less sensitive to changes to allow for new innovative solutions
	Devoting financial resources and manpower to develop technology and processes to become more change-capable
	Install windows, new and reused, so that they are easy to dismantle and thus have circularity in mind
	Increase their stockholding/inventory space, to meet the need for longer warehousing periods for temporary assets, i.e., windows
Collaboration	There must be greater degree of collaboration between the different actors/stakeholders involved as well as a within the whole industry.
	The collaboration should include helping each other finding the windows needed and thus supply each other with materials that are not needed and/or become surplus.

What can be concluded from the study is that a large part of the above-mentioned barriers and improvement potentials are not directly linked to prefabrication, even though they all have an impact on this type of construction process. These are likely to be cross-sectoral. What can be highlighted is that in cases where windows are not suitable for reuse in prefabricated buildings and/or multi-family houses, they can still be used in other areas where the requirements are not as high, e.g., in garages or cottages. The study has provided an insight into how the implementation of reused windows in prefabricated multi-family housing can be facilitated and what business decisions need to be made. However, exactly when and how this implementation will affect these businesses remains a bit of unknown ground even after this study.

5.6.2 Suggestions for further research

This report has mostly examined soft parameters such as collaboration between stakeholders, their respective responsibilities, generalized business strategical changes etc. and only highlighted factors such as cost, environmental impact, technical conditions and more. To get as concrete and adequate results about the impact and precise tools needed for an implementation of reused windows in industrial house production, further research could contribute. Here are some suggestions for further research areas that can contribute to a deeper understanding and more concretized answers to the research questions.

Cost-, quantity- and environmental impact calculations
Performing accurate cost estimates, calculating future flows and assets on the number of secondary windows, and performing detailed LCA analyses would have provided more accurate data of value to companies interested in this type of implementation. For example, if we had found arbitrary statistics on what types of windows are installed in Sweden, when they were installed and the number of each type, rough estimates of the number of windows entering the reuse-market could have been made. This would probably also have given an estimate of when the market will expand. This would have offered companies with a similar business structure to the company investigated in the study a stronger basis to stand on when facing business model changes.

Multi-business research
This study, specifically the interview study, has been largely based on a researched company and its conditions and partners. All construction companies in Sweden working in the field of prefabrication probably do not work with the same conditions or methods, which means that the results of this study are probably biased in their parts to the company studied. In order to obtain a cross-sectoral result, all interviews, or proposed interviews, should have been conducted with a number of enterprises in this field of work.

Design for Disassembly
A topic that would need its own study, but which has emerged during the study, is the issue of DfD in industrial construction and how this would have facilitated the future work of extracting a larger quantity of windows from the existing building stock for new production. Although the subject of this is only vaguely highlighted, Craftsmen A and B and the Senior Window Advisor, among others, mentioned that today's window fixtures make it much easier to extract. What is missing is careful information management on which windows are installed in which building, which could be a process to adopt. It can be speculated that the studied company could have obtained an arbitrary circularity on its own windows, and other components, if a total DfD were to be applied.

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Appendix

These questions were addressed in all interviews, with some modifications depending on the role of the interviewee. The wording and order of the questions varied according to the development of the interviews. The number of follow-up questions varied widely, again depending on how the interviews progressed.

1. Can you tell us more about yourself and your specific role?
2. Do you have any previous experience of working with reused components in construction projects?
    a. What kind of components?
    b. Have you experienced any interest from the sector in reusing windows?
3. What opportunities/difficulties do you experience in building apartment buildings with reused windows?
4. Which actor(s) in the value chain do you feel has the greatest influence for the implementation of remanufactured components?
5. Is there any actor that is expected to do more for a larger implementation?
6. In your specific role, can you do anything to ensure that the reuse of windows can be carried out to a greater extent?
7. Which actors in the value chain do you see a strong need to have a good cooperation with, in order for window reuse to become a more self-sustaining and functioning business?
8. How would increased demands for reuse in the construction sector affect you and your role?
    a. Would your way of working change, and if so, how?
9. What changes to your business model/business structure would need to be made for reused windows to become a viable business?
10. What first steps would you say Derome needs to take?
11. How would you say the conditions for reuse of windows in prefabrication differ from site-built projects?
    a. What is the main difference?
    b. What are the opportunities and difficulties?

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