The environmental benefits of relocating buildings

A study towards a more circular building sector

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Master thesis in Energy-efficient and Environmental Buildings
Faculty of Engineering | Lund University

Lund University

Lund University, with eight faculties and several research centres and specialized institutes, is the largest establishment for research and higher education in Scandinavia. The main part of the University is situated in the small city of Lund which has about 112 000 inhabitants. A number of departments for research and education are, however, located in Malmö. Lund University was founded in 1666 and has today a total staff of 6 000 employees and 47 000 students attending 280 degree programmes and 2 300 subject courses offered by 63 departments.

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The degree project is the final part of the master programme leading to a Master of Science (120 credits) in Energy-efficient and Environmental Buildings.

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Abstract

As the climate on earth deteriorates, actions are carried out within Europe to limit the amount of hazardous emissions to lower the environmental consequences due to greenhouse gases. A significant proportion of the emissions can be linked to the construction sector and its use of virgin resources. An area with great development potential within the construction sector is linked to its management and generating waste from demolition work. The Waste Hierarchy taken on by the EU states that to achieve sustainable use of resources, waste should primarily be avoided, and further materials should be reused. One strategy to avoid waste and prevent buildings from being demolished is to relocate buildings and thus extend their lifespans.

One way to decrease the climate impact of the building industry is to reuse buildings. They can be relocated if they are not situated in the right location. Today in Kiruna, Sweden, there is a major urban transformation where buildings in the city are being relocated to new sites requiring considerable effort and associated procedures. The primary objective of the relocation initiative is to conserve the cultural significance associated with the city. The present study aims to examine the climate impact that may arise from the relocation of a building (Case A) and to compare this impact to that of demolishing and constructing a new structure of comparable size (Case B). This investigation will be conducted through a life cycle assessment (LCA) methodology.

As a base for this study, a case building in Åre, Sweden, was assessed using LCA, where the relocation processes were based on interviews with a relocation company. The data collected from the conducted interview formed the scope of Case A. The relocation process was compared to a case study building that was demolished, and replaced by a newly constructed building that will represent Case B. Furthermore, an analysis of various factors, including different energy uses for Case A, calculation approaches for transportation of the relocation, and varying distances for the relocation to different cities utilising different emission factors for district heating was evaluated. To consider the potential benefits of the relocation in regard to the reuse, the amount of materials saved due to the relocation was evaluated, and the climate impact that would have been necessary to reproduce the saved materials was investigated.

The results of the LCA for the two cases were divided into two segments. The first segment compared the two cases excluding their climate impact related to the energy use for space heating and domestic hot water use. The outcome of the first segment resulted for Case A in 115 kg CO_2e / m^2 BTA and for Case B 208 CO_2e / m^2 BTA.

In the second segment, different energy needs were implemented for Case A and Case B to investigate the impact of energy use on the total climate impact. Different geographical locations for district heating were applied with varying emission factors to calculate an climate impact payback time. The results showed that the longest payback time was obtained when the building was relocated to Malmö, which can be linked to the low emission factor for the energy source used in that scenario.

The study results show that it is environmentally beneficial to relocate a building instead of demolishing it and constructing a new one. The most significant difference in climate impact between the two cases is related to the reuse of materials in Case A, which reduces the need to produce new materials.

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1 Introduction

In 2020, the European Commission presented a strategy to advance the EU's transition toward a circular economy. The initiative was presented as a measure of the world's challenges regarding impending climate change. The sustainability challenges linked to crucial value chains were proclaimed as areas requiring urgent and coordinated actions, contributing to the climate crisis. The European Commission considered the building and construction sector as an area with great potential for improvement, with a focus on efficient material processing and increased management of construction and demolition waste (C&DW)(European Commission & Directorate-General for Environment, 2020).

In addition to the guidelines set at the European level, Sweden has applied the national environmental objectives system, consisting of a generational goal and 16 environmental quality objectives. The National Board of Housing, Building, and Planning believe that if Sweden is to reach the objectives of a well-built and non-toxic environment, the quantity and toxicity of construction and demolition waste (C&DW) must be reduced (Boverket, 2023b). Furthermore, Milestone targets have been presented to facilitate essential steps to achieve the overlying objectives. One of the targets states that preparatory work for reuse, material recycling, and further recycling of non-hazardous C&DW needs to reach a percentage increase of 70% in weight by 2025 (Environmental Objectives Council, 2022).

In 1975, the European Union introduced a new directive, the Waste Framework Directive, to motivate the sustainable use of resources and reduce the environmental impact of waste generation and waste management. This resulted in the waste hierarchy, a description of how waste should be handled (EC, 1975). Since the first version was introduced, the framework has subsequently been updated to its current version 2008/98/EC, implementing a more detailed description of the waste hierarchy. In the current framework, the waste hierarchy consists of 5 steps for how waste should be treated, see Figure 1. The order of priority is based on the most preferred measure to avoid waste such as prevention followed by reuse and recycling to the last measure of disposal (EC, 2008).

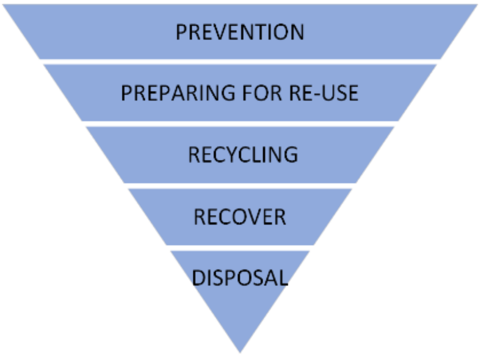

Figure 1 The Waste Hierarchy according to EU's directive 2008/98/EC

In addition to this directive, Sweden has chosen to include the waste hierarchy in Chapter 15 § 10 of the Environmental Code. Further, in Chapter 2 § 5, it is stated that everyone who runs a business or takes an action must economize on raw materials and energy, indicating that actors have an obligation to use the opportunities to take waste prevention measures (Miljöbalk (1998:808), 2022).

Laws and directives implemented at the European and national level show that there are strategies and guidelines on how waste and material resources should be treated. In Sweden, there are further initiatives to promote a sustainable construction sector focusing on resource efficiency. LFM30 is a local strategic plan implemented in Malmö, Sweden, ensuring the transition towards a climate neutral construction sector. The strategic plan is divided into six areas with development potential with associated strategies for how these are to be implemented, with one area focused on circular economy and resource efficiency. Previously conducted studies present results which indicate how the reuse of materials is an important step to increasing resource efficiency. Today it has generally been implemented on single elements of buildings, such as windows and doors, walls, and installations (LFM30, 2021).

Another organisation promoting the development of a circular building sector is the Center for Circular Building (CCBuild). The project aims to create conditions for circular material flows in the construction sector where waste can be reused, and the extraction of virgin materials can be reduced. Like LFM30, CCBuild consists of several actors who work to increase knowledge regarding the subject of circularity (IVL, n.d.). A study conducted by Wennsjö et. al. in collaboration with CCBuild investigated the potential of a large-scale market for reuse in Sweden. To enable the establishment of a reuse market, it is of great importance that existing actors in the building sector include more reuse in their business model. According to Wennsjö et. al. an important incentive to promote increased use of reused materials is to demonstrate the potential environmental benefits that can be achieved. (Wennesjö et al., 2021).

The present discourse advocates for the implementation of effective measures towards reducing construction and demolition waste related to the building sector. In connection with the European Parliament introducing directives to promote the transition to a circular society, the importance of more efficient use of existing resources is enhanced. An adaptation of the circular model in the building sector would highlight the preservation of materials and thus, potentially extend the material’s lifespan.

This study aimed to generate an alternative solution instead of having to demolish buildings. In this study, therefore, an alternative strategy was investigated which encompasses the relocation of a building to a new location as a solution to prevent the building from being demolished and thus reducing the generation of C&DW. The study aims to contribute as a circular alternative in the decision-making when buildings can no longer remain in their current location and must be demolished.

1.1 Aim and Objectives

This study aims to analyse the potential climate impact when relocating a building. The study also aims to investigate the current practises used when relocating buildings to create a methodology to evaluate the climate impacts based on the Life Cycle Assessment method. The extent and timing of important contributing factors can be identified by dividing the whole procedure into specific processes. Furthermore, a comparison will be conducted between the process of relocating a building and the linear process of demolishing the building and constructing a new building. The comparison aims to highlight how material usage differentiates and which case is more environmentally beneficial.

The study aims to answer the following questions:

- What potential climate impacts are generated when relocating a building?
- What are the key contributors to the climate impact when relocating a building?
- How does the result in climate impact differ in the case of relocating a building compared to demolishing and constructing a new building?

1.2 Delimitation

Presented below are the main delimitations implemented in this study. Additional limitations that arose during the execution of the study are further described in the report.

- Potential economic and social impacts.
- Construction calculations.
- Load-bearing properties of roads.
- Energy simulations.
- Impact categories were limited to climate impact.

1.3 Background

The background to this work comes from a problem statement presented by the property developer Resona Utveckling AB. Their problem concerned the management of existing buildings where new buildings are planned to be constructed due to exploitation in Stockholm, Sweden. This implies that the existing buildings must be dismantled to accommodate the new buildings. The opportunity was raised to investigate the possibility of relocation of the existing buildings as these are well-functioning buildings and to discover the potential environmental benefits. To calculate the potential environmental impact of a possible relocation, the company provided a case study building that was previously inventoried for its constituent materials, located in Åre in Sweden.

The case study building was constructed in the 1950s as a two-storey souterrain house consisting of a basement, main floor, and cold attic, shown in Figure 2. The gross floor area, later described as BTA, is approximately 260 m^2, and the heated floor area is 183 m^2. The structural frame is mainly constructed of the lightweight concrete material *Ytong*, produced in Sweden during the 1950s. Additional materials have been added to the building through renovations and extensions. A new garage was constructed, the original wooden porch was expanded, and new interior- and exterior façade materials were added. Timings and documentation on materials added during renovations were not available when the study was conducted. The building’s main components are summarised in Table 1

Figure 2 Picture of the south-facing facade of the case study building. Picture obtained from Google maps

Basement

The building's foundation consists of a slab on the ground with reinforcements along the building's load-bearing walls. The floor surface in the basement is bare concrete except in four rooms were it is covered with plastic carpet. The basement includes three types of walls: Exterior walls, a central loadbearing interior wall and non-loadbearing interior walls. The exterior walls are divided into two different constructions due to the shifting elevation of the ground. Exterior walls facing north, east and west are partially underground and consist of asphalt and cement on the external side, followed by a loadbearing layer of concrete masonry unit and a wood fibre insulation board on the interior side. The south-facing walls have the same loadbearing element but with a façade plaster on the exterior side and no insulation on the interior side. The interior walls of the building are made of lightweight concrete and plaster on the surface and are constructed in two thicknesses of 70 mm and 200 mm.

Intermediate floor

The floor structure on the main floor consists of reinforced concrete in the bottom layer, followed by 45 mm x 95 mm wooden beams with a c/c of 0.6 meters. The floor surface is composed of parquet, ceramic tiles, stone tiles, and plastic carpet, differing in the different rooms.

Attic and roof

The floor in the cold attic is made up of gypsum on the bottom layer which was used as the interior ceiling. Following, a layer of wooden beams and loose wood fibre insulation is placed on top of the gypsum. Wooden W-trusses with a c/c of 1.2 meters are placed on top of the attic floor. The roof consists of a layer of rough planed followed by substrate board and steel sheeting on the exterior side.

Additional building elements

Additional building elements are an internal staircase, wooden porch, staircase leading to the main entrance and two chimneys constructed with masonry bricks. The internal staircase is constructed in concrete, and the external staircase is constructed in sheet steel.

Table 1 Summary of building elements with included materials

Building systems	**Main Building Materials**
Basement	Concrete, Reinforcement steel, insulation boards
Structural Walls	Lightweight concrete, Concrete Masonry Units
Non-Structural Walls	Lightweight concrete
Wall surface	Plaster, Wood cladding
Floors	Concrete, Reinforcement steel, wooden beams
Floor surface	Parquet, ceramic tiles, Stone tiles, Plastic
Ceiling	Gypsum
Doors and Windows	Wood frame, glass, plastic, aluminium
Attic	Loose wood fibre insulation, wooden beams
Roof construction	Wooden W-trusses, Wood, substrate board, steel sheeting
Additional Constructions	Concrete, reinforcement steel, wood, sheet steel, Impregnated timber, Masonry Brick

2 Literature Review

A literature review was conducted for the study to provide a comprehensive understanding of the existing research connected to the subject and identify potential research gaps for further examination. Moreover, a literature review was included to give an extensive description of the concepts implemented in this study.

2.1 Circularity in the building sector

The linear approach to resource use needs to be revised for addressing the environmental challenges that lie ahead. This approach assumes that resources are infinite, and this perspective is deeply ingrained in our societal values. In contrast, a circular economy model aims to promote sustainable development by reducing the potential environmental impacts of the building sector. This shift toward circularity represents a promising strategy for achieving sustainable welfare (Hartley et al., 2020).

The circular economy model, which has been widely disseminated by the Ellen MacArthur Foundation, emphasises the potential for integrating various stages within the lifespan of a product or system to facilitate more efficient use of materials (Ellen MacArthur Foundation, n.d.). The preservation of materials through design for longevity is highlighted as a means of maintaining the value of energy and labour expended. Recycling, in contrast, to reuse, often results in material loss and reduced embedded energy (*The Circular Economy in Detail*, n.d.).

The building sector is recognised as a significant contributor to greenhouse gas emissions worldwide, primarily due to the carbon footprint associated with the materials used in construction. The reduction of this impact can be significantly enhanced through the practice of reusing well-functioning materials rather than resorting to recycling or demolition. Adopting a more circular approach to construction is one potential solution, which involves implementing the 3R framework of "Reuse, Recycle, and Recovery" instead of the traditional "Take, Make, and Dispose" paradigm. (Larsen et al., 2022).

As a strategy to achieve the national environmental- and climate goals, the Swedish government initiated an investigation into how the transition towards a circular construction sector should be completed. This through that CE approach should be implemented by integrating sustainable production and design and facilitating innovation and methods within the sectors (*Cirkulär Ekonomi-Strategi För Omställningen i Sverige*, n.d.).

2.2 Life Cycle Assessment

Life cycle assessment (LCA) is a method for assessing the potential environmental impact of a product system throughout the life cycle, from extraction and acquisition of raw materials to end-of-life treatment and final disposal. The provided results of an LCA are expressed in different environmental impact categories, divided into endpoints and mid-points. Where commonly used environmental categorises are Global Warming Potential (GWP, kg CO_2e) also referred to as climate impact, Acidification Potential (AP, SO_2e), and Eutrophication Potential (EP, PO_4e). To provide data on the product's potential environmental impact for modules, these can be expressed in Environmental product declarations (EPD). The method behind performing an LCA is standardised in the international standard ISO 14040. The methodology is divided into phases, describing the four parts required to perform a complete LCA: Goal and Scope, Life cycle Inventory, Life cycle Impact assessment, and Life Cycle Interpretation. According to the ISO 14040 standard, the process of performing an LCA should be treated as iterative, where individual phases are influenced by the results of the other steps (International Organization for Standardization, 2006.). The iterative workflow of an LCA is shown in Figure 3, describing the relations between the four steps.

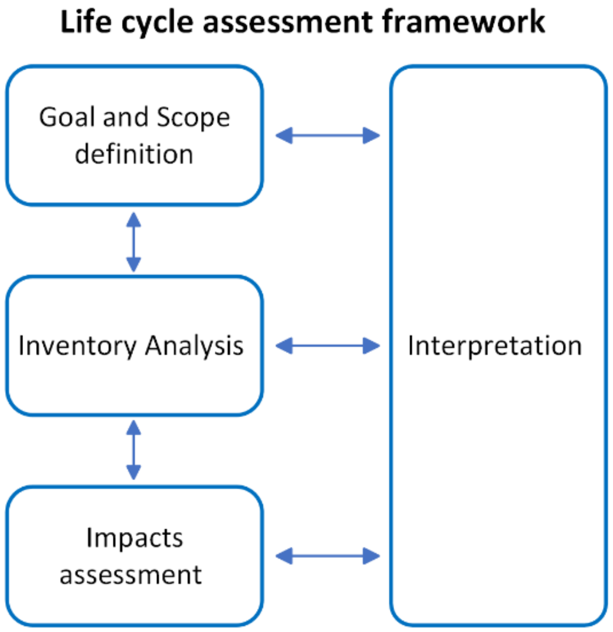

Figure 3 Integrated process of performing an LCA according to ISO – 14040

For the research within the LCA field, there are challenges to address. The challenges were divided up into areas consisting of *functional units, system boundaries, inventory analysis, impact assessment* and *beyond LCA*. Regarding the significant issues for the functional unit, it is connected to the variation used for different functional units resulting in complications when comparing LCAs. Uncertainties regarding the calculated impact compared to the actual impact since the market might require reconstruction or demolition of a building before the end of its lifetime, which is connected to problems for the impact assessment. Dilemmas occurring in the system boundaries are mainly caused by missing data for refurbishment and the lack of procedure for selecting the appropriate system boundaries. Reoccurring is the missing data and uncertainties in the collection of the potential impacts for both new and old materials. When it comes to the brought-up areas and challenges the development within the field of LCA must continue (Anand & Amor, 2017).

2.2.1 Regulations of Life Cycle Assessments in the construction sector

In Sweden, guidelines and regulations on how to perform the LCA method on buildings are regulated under the EN-15978 standard, *"Sustainability of construction works – Assessment of environmental performance of buildings – Calculation method"*. The purpose of EN-15978 is to support decision-making and data collection in the environmental performances of buildings. The standard defines the different stages of a building's life cycle as information modules, which account for the environmental burden specific to the processes within each stage. The standard divides assessment into four modules: A, B, C and D (European Committee for Standardization, 2011)

Module A

The first stage (A) is divided into a product stage and a construction process stage, shown in Table 2. The product stage accounts for the environmental impact connected to the product, starting with the extraction of raw material, transportation to the production location and the product's manufacturing. The construction process stage accounts for the transportation to the construction site and processes related to the construction and installation of the building.

Table 2 Modules included in the construction stage according to EN-15978

Product stage	A1	Raw material supply
	A2	Transport
	A3	Manufacturing
Construction process stage	A4	Transport
	A5	Construction and installation

Module B
The second stage (B) refers to the usage stage of the building. It covers all potential processes from the period of the finalised construction to the time of demolition. Module B1 (Use) encompasses impacts arising from the normal use of the component in a building, which according to the EN-15978 standard, for example, includes the release of substances from facades, roofs, and floor coverings. Module B1 (Use) encompasses impacts arising from the regular use of the component in a building, which according to the EN-15978 standard, for example, includes the release of substances from facades, roofs, and floor coverings. Module B2 (Maintenance) includes processes linked to the maintenance of the building's functional, technical, and aesthetic performance. Module B3 (Repair) encompasses the repair of damaged components in the building and includes all processes that occur in connection with the repair. Module B4 (Replacement) deals with all operations linked to the replacements of building components, and Module B5 (Refurbishments) includes processes related to the renovation of the building component. If the measures result in the building's performance changing, this should be considered, and a new assessment should be conducted (European Committee for Standardization, 2011).

Furthermore, in modules B2 – B5, when new products are implemented in the building, processes linked to the production and transport of the new materials, installation, and waste management are added. The extent of repairments, refurbishments and replacements are estimated based on the lifespan of different materials and products (Scheuer et al., 2003). Modules included in the use stage are shown in Table 3.

Table 3 Modules included in the use stage according to EN-15978

Use stage	B1	Use
	B2	Maintenance
	B3	Repair
	B4	Refurbishment
	B5	Replacement
	B6	Operational energy use
	B7	Operational water use

Module C
The third module (C), accounts for the process of demolition and deconstruction of the building presented in Table 4. The End of life stage (EoL) is initiated when the building is no longer intended for further use. The module is divided into four processes of waste management from demolition and deconstruction to the final disposal of material. The first module, C1 (Deconstruction demolition) considers the emissions from operations and work required for demolition at the site. C2 (Transport) is the transportation to the disposal site or when the end of the waste-state is reached for the material. The transportation can include intermediate storage if required. C3 (Waste processing) pertains to the management of construction waste with the objective of its potential reuse, recycling, or recovery. Module C4 (Disposal) specifically focuses on the emissions generated during the physical treatment and handling of waste at the disposal site.

Table 4 Modules included in the end-of-life stage according to EN-15978

End of life stage	C1	Deconstruction demolition
	C2	Transport
	C3	Waste processing
	C4	Disposal

Module D

The last Module (D) works as a supplementary stage to the building's lifecycle and is used for assessing potential environmental effects beyond the analysed building depicted in Table 5. Results generated from module D quantified are as net benefits or loads. Examples of potential net benefits are mentioned in the IVLs report on environmental effects of reuse, where it could be generated from energy transferred from PV-systems or effects of utilizing building material for reuse or recycling which reduces the need for new materials. (Gerhardsson et al., 2020a).

Table 5 Modules included in stage D according to EN-15978

Benefits and loads beyond the system boundary	D	Reuse
	D	Recovery
	D	Recycling

For each module, the results can vary depending on many factors i.e., what type of building material or the energy source is being used for the project. Though, similarities in the contribution of respective modules can be seen in conducted LCAs of buildings where the highest potential environmental impact occurred during stage A and stage B (Erlandsson et al., n.d.).

In stage A, the impact related to the product stage (A1 - A3) is typically the most significant when assessing the climate impact of a building. In a study conducted in Sweden for an apartment building with different frame structures, it was found that A1 - A3 accounted for the highest contribution in the A-stage, with concrete and wood components having the highest impact (Liljenström et al., n.d.). When comparing the impacts of different building materials and systems, A1 - A3 was still found to be the most significant contributor, although the values varied greatly depending on the type of material used. Specifically, the use of KL-timber as the frame of the building resulted in an impact of 167 kg CO_2 e/A_{temp}, while the highest impact was observed for concrete as a frame with 279 kg CO_2 e/A_{temp} (Erlandsson et al., 2018).

Transportation emissions occur throughout all the stages within the LCA but mainly in the A-stage and C-stage. There are different calculation methods used when considering the amount of potential impact that certain types of vehicles have dependent on the transportation distance. A study was conducted comparing different scenarios of transportation which included a case of real fuel consumption and cases with a variation in distances to the site and the amount of material considered in the transport. The results indicated the importance of the quantification of material that is being transported which highly influenced the results. The authors also emphasise the importance of defining the distances of transportation needed for materials (Hadjiiski et al., 2022).

During the construction phase, the building site is usually acquired to use heavy machinery and in demand of transportation of building materials. Diesel is commonly used as a fuel for machinery, which contributes to a high amount of greenhouse emissions. In a previous study, it was shown that environmental impacts were related to the machinery's operational weight. This was mainly caused by the great amount of consumption of fuel that heavier machinery has during its operation. The impact occurring for the production and consumption of diesel fuel was highly correlated to the machine's lifetime, fuel efficiency and operational efficiency (Ebrahimi et al., n.d.).

The contribution of climate impact is usually the least significant factor in the building during the end of life stage (EoL). However, depending on how the material in the module is handled the result can differ. A study conducted by varying different EoL scenarios indicated how the results in the different stages depended on if the building was demolished or dismantled (Quéheille et al., 2022). Like the differentiation observed in the A-stage impacts of different building materials and systems, the impacts of EoL also vary depending on the type of material used.

Lastly "Benefits and loads beyond the system boundary" equivalent to the D-module as mentioned earlier is uncommonly included for the LCA of buildings since it is optional. The principle of reuse and recycling can have climate impact reductions when being implemented. In a previous study, it was shown that these potential savings were larger than transportation, construction and EoL impacts (Wastiels et al., n.d.).

In another study, the use of module D resulted in a negative impact, noting that a negative impact should be considered as positive in terms of LCA since it is a reduction. The main contributor to the improved result in the module is the recyclability of building materials caused by the renovation of the case study building. Also in this study, the installed photovoltaics contributed, where the energy generated could be exported. For both these studies, the main contributor to the improved result using module D, was the recyclability of steel (Wastiels et al., 2013).

The procedures recommended to reduce the potential impacts considering the A-phase are connected to the early design phase, with careful selection of options for the type of material, depending on the function that the material should fulfil. Also, transportation options are brought up if the material is transported by trains, lorries or other types of transportation which should be considered and evaluated, together with the type of fuel used for the transportation. Another important aspect is the implementation of energy efficiency during the operational phase. During the use-phase limitations are already considered as the buildings should fulfil the set requirements for energy use (Erlandsson et al., 2018).

2.2.2 LCA in Sweden – Climate declaration

In 2022, Sweden implemented a new legislation, named Climate declaration, that requires developers to report climate impacts addressed in GWP (kg CO_2e) for the construction of new buildings. The Climate declaration covers emissions linked to stages A1 – A5 in the EN-15978 standard. One reason for the implementation of the legislation is based on studies which demonstrate that the construction stage accounts for a large part of the total climate impact throughout the building's life cycle. The legislation was planned to be implemented gradually in two steps, referred to as Climate declaration 2022 and 2027 (Boverket, 2020).

In the climate declaration, it is required by the developer to report CO_2e emissions from stages A1 – A5 for materials in three building elements: Load bearing construction, internal walls, and envelope (Boverket, 2020). It has previously been common to exclude module A5 from the LCAs since they are typically assessed during design phases, causing uncertainties about the processes that will be implemented in the construction of the building. To simplify the implementation, Sweden chose to divide information module A5 into five distinct segments. The purpose behind the division was to enhance the clarity of what the construction and installation process normally consists of and simplify the processes of implementing A5 in LCA (Erlandsson, 2018). The structure of the information module is presented is shown in Table 6.

Table 6 Module A5 is divided into five underlying information modules describing the processes occurring during the construction and installation process.

A5 - Construction and Installation	A5.1	Waste, packaging, and waste management
	A5.2	Construction site vehicles, machinery, and equipment (energy to fuels etc.)
	A5.3	Temporary sheds, offices, storage, and other buildings (energy for heating, etc.)
	A5.4	Other energy products used during the construction process (such as propane and diesel for heaters, purchased electricity, district heating, etc.)
	A5.5	A5.5 Other environmental impacts from the construction process, including eutrophication during blasting, land exploitation, chemical use, etc

Moreover, the A5-module was further simplified by combining the subcategories into two main categories: A5 Waste and A5 Energy. A5 waste, covering A5.1, accounts for emissions generated in the production stage and in connection with transportation to the construction site. This is measured through a percentage supplement for waste linked to each specific building material. A5 Energy, covering A5.2 – A5.4, accounts for emissions generated through electricity, heating and fuel used on the construction site. A standardized value for A5 energy was introduced through a study conducted in 2021, determining the potential environmental impacts of building three categories of building types. The study was conducted on 36 buildings and resulted in approximated values for one- and two-dwelling buildings are shown in Table 7 (Malmqvist et al., 2021).

Table 7 Standard value for A5 Energy divided into different energy sources

Energy source	**Description**	**One- and two-dwelling buildings** ($kg\ CO_2\ e/m^2$, BTA)
Electricity	Electricity for the operation of sheds and lighting, equipment and elevators connected to the building during construction	8.7
District heating	District heating for hot water and heating of sheds, building during construction, and partial drying of cast-in-place concrete.	0
Diesel	Fuel for transportation, mobile cranes and snow removal, excl. groundworks	2.2
Petroleum gas	Radiant heat for ensuring strength when casting concrete joists and partially for plaster and masonry work	0
Heating oil	Heating before other heating sources is established, the casting of foundation.	0
Total A5 Energy		**10.8**

New building components and additional steps in the building's life cycle will be introduced when the 2027 regulation takes effect. This implies that installations and internal surface layers and furniture will be added to the existing building elements already included in the legislation. Furthermore, additional life cycle stages such as B2, B4, and B6 in the use stage, and C1 - C4 in the End-of-Life stage will be included (Boverket, 2020).

To simplify the implementation of the new building parts, standard values for each category have been introduced for different building types. The standard values are estimated based on quantities of materials used in the different installations of a selection of studied buildings in Sweden. Emissions linked to technical installation systems were divided into four subcategories: Ventilation, Heating, Electricity and Elevator. The first three parameters are accounted for when assessing single-family houses. Ventilation is based on materials used for ducts and air handling units. Additionally, single-family houses also include heat pump and floor heating components. Heating and sanitation include piping for water, sewage, heating, and radiators.

Electricity is based on the material used for cables, cable ladders and lighting fixtures (Malmqvist et al., 2021). Values are presented in Table 8.

Table 8 Standard values of emissions for installation in one- and two-dwelling buildings

Stages (kg CO_2e/m^2, A_{temp})	**Ventilation**	**Heating and sanitation**	**Electricity**	**Total**
A1 – A3	7.1	2	2.1	**11.1**
A4	0.16	0.05	0.04	**0.25**
A5 Waste	0.1	0.27	0.12	**0.49**
Sum				**11.84**

2.3 LCA method connected to a circular economy.

Implementing the Circular Economy (CE) model for assessing savings in economic, environmental, and social areas is upcoming. Through LCA the potential environmental savings can be discovered. The primary focus of the studies using CE and integrating it with LCA is the potential measures that can be made with construction waste and demolition waste. Reuse, recycle and recovery is the approach considered for the CE model where recycling is the most prominent of these, especially regarding construction and demolition waste. The authors point out the need for research on the possibilities of reuse, and prevention of demolition. Overall, the study indicates that adopting a CE model combined with LCA can potentially reduce the impacts on several environmental categories. With a circular economy in mind, adapting the LCA method, creates potential opportunities for which measures to apply regarding building materials and the type of material management. With a circular economy in mind, adapting the LCA method creates potential opportunities for which measures to apply regarding building materials and the type of material management. The choice of reuse or recycle might differ dependent on the circumstance for the type of material that is considered (Ghisellini et al., 2018).

Predominantly when applying the CE model to the building sector the focus has been on recycling where materials such as concrete and steel are the most common materials. Recycling can be beneficial as it decreases landfilling and contributes to lower greenhouse gas emissions, however the authors emphasize the possibilities of reuse. In a study conducted comparing the reuse and recycling of building materials such as steel, timber, and plasterboards the results indicated that the potential savings that reuse had over recycling could be 64% for GWP and 23% for ozone depletion potential which were the major savings compared to the other environmental categories. The study also brings up major barriers regarding the circular economy in the construction and real estate sectors. One of the major dilemmas is the monolith structures, which are constructions that cannot be disassembled and therefore, difficulties occur for reuse. As for the other barrier it accounts for non-standardized building measures whereas the building components for these types of buildings do not match the design of others (Minunno et al., 2020).

The implementation of a CE model is impeded by various obstacles, including economic, legislative, managerial, and informational factors. These hindrances serve as barriers to the adoption of reuse, recycling, and recovery practices. However, the primary contributing factor to this issue is the lack of awareness and understanding regarding the composition of materials, as well as the potential for their reuse or recycling. Additionally, the potential reduction of environmental impact that could result from implementing a CE framework is often overlooked (Ghisellini et al., 2018).

2.4 Dilemmas connected to reuse of building material.

The building sector is among the most resource-intensive industries, and its operations from construction to demolition generate a significant amount of waste, contributing to approximately 30% of Europe's total waste production. However, this also presents an opportunity for the reuse of construction and demolition waste (C&DW) (Meex et al., 2018).

The reuse of building waste has the potential to generate substantial energy savings, with the magnitude ranging from 20 % to 40 %, contingent upon the efficiency of recycling practices. The study estimates that the energy savings resulting from such recycling efforts are equivalent to heating approximately 200,000 single-family houses for one year. Metal, wood, natural stone, and mineral wool are identified as the most advantageous building materials to conserve in terms of energy and reuse. The authors underscore the significance of reusing mineral wool, as it offers a significant contribution to the total energy-saving potential (Thormark, 2001).

A significant challenge associated with the reuse of building materials from existing structures is the inadequate availability of information. Demolition and deconstruction are commonly perceived as the most cost- and time- effective approaches, thereby hindering the adoption of reuse practices. To promote the implementation of a more sustainable approach to the construction sector from both environmental and economic perspectives, it is essential to establish standards, methodologies, and codes that enhance the overall knowledge of reusing existing materials in new construction projects. Furthermore, design decisions made during the initial stages of a project should consider the identification of potentially valuable materials that could be reused (Gorgolewski, 2008).

The determination of the appropriate procedure for recovering, reusing, or recycling building materials is contingent upon the specific type of material used for each building component, as this factor determines the feasibility of such actions. Moreover, the potential reusability of the building material is also dependent on the method employed to dispose of the building, including demolition, deconstruction, or repurposing (Assefa & Ambler, 2017).

A study examines the challenges associated with Sweden's building sector in its transition towards reuse and circularity, revealing the presence of an immature market, an underdeveloped value chain, and an insufficient supply for reuse. Considering these barriers, the report recommends increasing the overall awareness and knowledge regarding the reuse of building materials with exemplary cases. Additionally, it proposes the implementation of incentives for reuse and the development of long-term strategies to facilitate the reuse of building materials in the future (Säynäjoki et al., n.d.).

2.4.1 Waste management of today

Potential emissions during demolition are estimated to constitute a smaller part of the total potential emissions generated during a building's life cycle (Erlandsson et al., 2018)(Rinne, Ilgin, & Karjalainen , 2022). The extent to which a material affects the building's total emissions during demolition can be linked to which processes are included in its waste management and how the material will be used in the future, i.e., reuse, recycle, incineration or disposal. Strategies of waste management for common building materials are shown below.

Concrete, being one of the most used building materials consists of aggregate, cement, and water. Most of the environmental impacts are linked to the production of cement, due to the combustion of fossil fuels and the release of carbon dioxide in the calcination process (Palm et al., 2015). The aggregate accounts for a smaller part of the environmental impacts, which mainly is caused by the transportation of the material. In the waste process of concrete, it is common to utilize the waste in two practices which are crushed and then used either as landfilling or as aggregate in the production of new concrete (Svensk Betong, n.d.).

Wood is a material which is usually used in combination with other building materials such as steel (nails, screws), plaster or insulation as well as paint. In the waste process, it can be divided into fractions of pure wood, wood-based boards, and impregnated wood. In Sweden, it is unusual to reuse or recycle wood products generated during the demolition of buildings due to the wide availability of the material. It is usually burned for energy recovery and the incineration plants vary depending on which fraction of the material is processed. (Johansson et al., 2017)

Gypsum boards are the typical form in which gypsum is found, and how the material is managed as waste largely depends on its condition. If the material is in good condition, it can be separated from the two surrounding paper surfaces and mixed into the production of new gypsum boards. The tendency of gypsum to break apart during demolition due to its material characteristics often poses a challenge for recycling. As a result, the material is often either deposited or subjected to energy recovery (Johansson et al., 2017). In Suarez et. al's study, the results show a reduction of over 50 % in kg CO_2e per ton from recycled gypsum compared to production with virgin raw material. The biggest impact in both cases can be linked process of drying the gypsum in a furnace. (Suárez et al., 2016)

At present, most of the steel used in construction and the resulting waste generated from demolition is processed through conventional methods of material recycling. The process of recycling the steel mainly consists of sorting and melting the steel. (Palm et al., 2015). According to Husson and Lagerqvist's study on the reuse of steel components, the primary production of steel results in an environmental impact approximately of 2000 kg CO_2e per ton. In a secondary production where the proportion of recycled steel is between 40-44%, the result is estimated at 520 kg CO_2e per ton, reducing the emissions by a quarter (Husson & Lagerqvist, 2018).

2.5 Opportunities for relocation and moving buildings and building materials

In Sweden, there has been a recent surge in relocating buildings, particularly in Kiruna, due to a major urban transformation. The relocation process commenced in 2017 with the first building out of 42 planned for relocation. The primary objective of the relocation initiative is to conserve the cultural significance associated with the city (Kiruna Kommun, n.d.).

In Sweden, the relocation of buildings is commonly carried out through three methods: volume moving, partial disassembly, and total disassembly. The selection of the relocation method is contingent on the building's condition and the surrounding circumstances. The volume moving method involves the transportation of the building in volumes, either as a single unit or divided. Typically, a new foundation is required for this type of relocation. Partial and total disassembly methods entail the deconstruction of the building envelope and its transportation to the new location, where it is reconstructed to preserve as much of the original structure as possible (*Boverket,* n.d.).

Previous studies have primarily focused on the relocation of houses as a means of preserving cultural heritage, while research examining the potential environmental benefits of this practice remains insufficient. There is a similarity between modular housing and relocating existing housing, per se both constructions are finalized, and both can be equally feasible for reuse dependent on the conditions of the constructions.

A trend in the building sector is the prefabricated construction method which is divided up into categories. Typically, modular housing is one of these methods where most of the building is constructed off-site and afterwards assembled and completed on a permanent foundation. Therefore, 75% - 85% of the work occurs off-site and 15% - 25% on-site. In a previous study, an LCA comparison of two types of modular houses and a conventional house was conducted which resulted in some advantages and disadvantages in the cases, it was noted that one of the primary advantages of modular houses is the savings during the off-site construction in terms of labour in one of the cases and the material required. What was also stated is that not in all cases for modular housing performs better than conventional regarding the potential environmental impact which can be a common claim. But the authors emphasise the potential to reduce environmental impact when applying the modular-construction technique (Kamali et al., 2019).

Another study utilised the benefits of the method of design for deconstruction (dFd) of modular components where possibilities of reusing material multiple times would have a potential environmental saving effect and compared that to a conventional building. The results indicated that for each successive reuse of materials the total environmental impact proportionally got reduced as the impact of acquired new raw materials was not needed. As a result, achieving the maximum amount of reuse indicated a reduction by a mean value of 60% - 70% compared a traditional building for impact categories climate impact and fossil fuel depletion. In the case when the dFd was not reused the results got drastically worse as it performed up to 5% - 30% worse than the traditional building, this problem could occur when the material was damaged and not possible for reuse. Therefore, it is stated adaptability and durability are the main concerns when applying a dFd-method (Eckelman et al., 2018).

3 Methodology

The methodology of this study describes the holistic approach of comparing the potential climate impact in a circular- and linear process linked to the preservation, demolition, and construction of building materials. The outline of the study is to investigate the potential climate impact of two cases where a selected case study building is relocated to a new site (Case A - circular) compared to constructing a new building (reference building) and demolishing the case study building (Case B - linear). The outline of the two cases is described below:

Outline Case A

- *Information of case study building is collected from technical description and drawings.*
- *The possibility of relocating the case study building is examined.*
- *Quantification of building materials that can be relocated is accounted for through modelling in Revit and post-processed in Excel.*
- *The LCA is conducted for the processes involved for the relocation of the building considering the required work at both the original and new site as well as the transportation process.*
- *Once the building is relocated and finalized the potential effect of energy use of space heating and domestic hot water is assessed of the potential climate impact.*

Outline Case B

- *Information is acquired of the average climate change potential of constructing a new one- and two-dwelling house.*
- *From the information acquired of the material from the case study building the potential impact of the complete demolition is assessed.*
- *Once the building is constructed and finalized the potential effect of energy use of space heating and domestic hot water is assessed of the potential climate impact.*

From the two outlines of the cases two comparisons, the first comparison presents the climate impact generated until the building is operating on the new site. The second comparison is based on the energy use when the building was put into use. The outcomes of the various stages in the LCA for the two cases will be presented in terms of GWP expressed in kg CO_2e to facilitate a comprehensive understanding of the results. The first comparison between the cases, before including energy use (B6), will be expressed in kg CO_2 / m^2 BTA. Subsequently, a comparison will be conducted by incorporating the implementation of B6, and the results will be expressed in terms of environmental payback-time.

The assessment of the potential climate impact of the building relocation process was conducted through interviews and data collection from a relocation company named Tunga Lyft. Prepared interview questions were aimed to receive a complete picture of which machinery, equipment and transportation that is involved in the construction work at the original site as well at the new site.

The design of the cases has been conducted based on chronological order and further on been reformulated to fit into the framework for LCA according to EN-15978. Environmental data for materials, machines and standard values have been selected based on OneClick LCA's climate database and previous studies related to the subject. Presented in Figure 4 is the conducted workflow for the study.

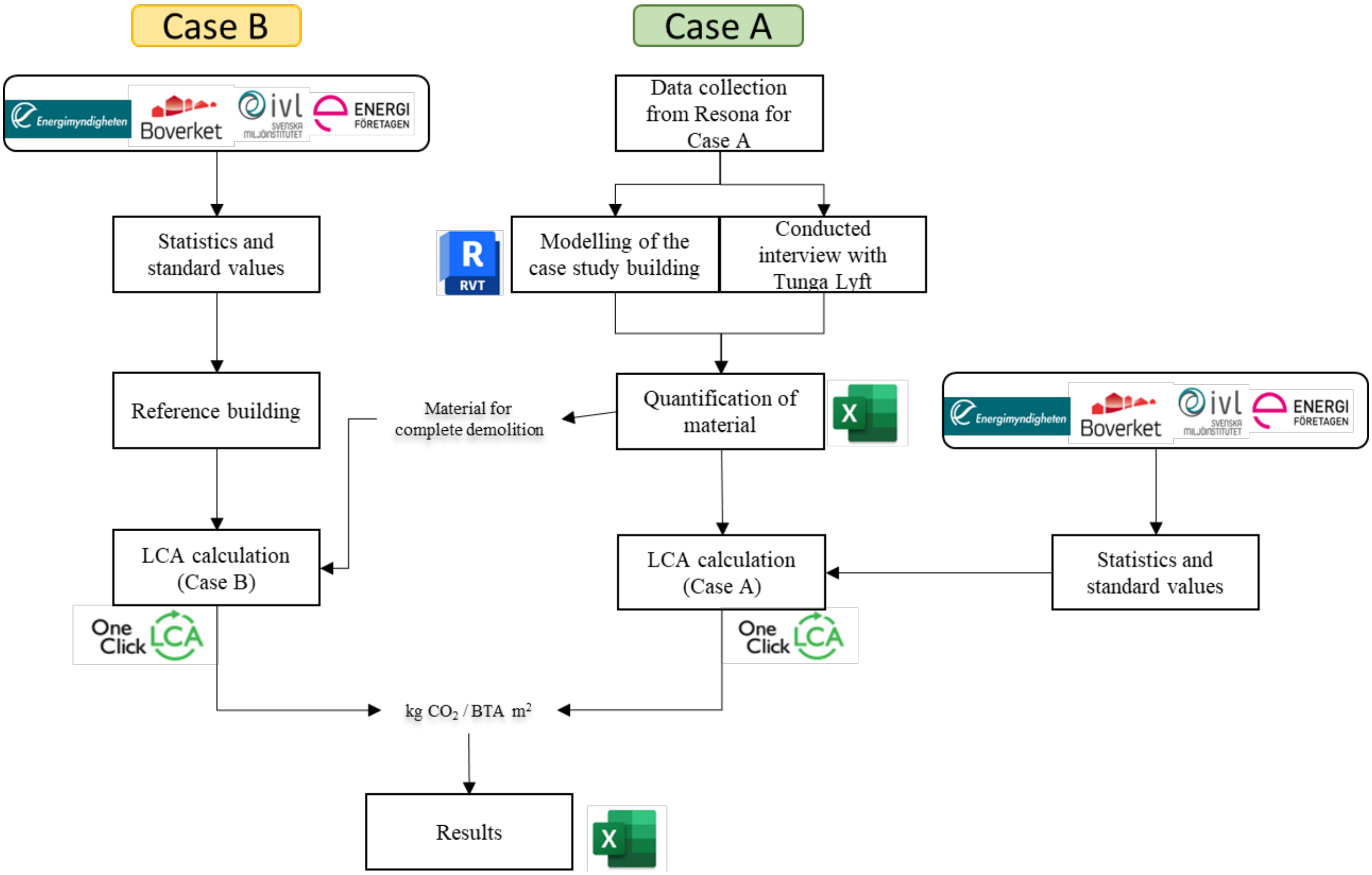

Figure 4 Schematic of the workflow of the study

3.1 Case study building

The first subchapter describes the methodology behind the data collection of materials and quantities from the case building, determined through drawings, technical descriptions, and pictures received from Resona. Based on the accumulated information, a 3D model was designed in Revit to compile and divided quantities to specific building systems. Furthermore, for potential missing information regarding details of construction parts assumptions of design was based on similar constructions from contemporary buildings from the 1950s in Sweden (Björk et al., 2013)(Björk et al., 2015) (Bodin et al., 2016).

3.2 Literature review

The literature review was conducted with the objective of gathering and assimilating information related to the chosen subject of the master's thesis. The purpose was to systematically gather and synthesize available literature from diverse sources, including public authorities and scientific reports. The sources utilized in the literature review were openly sourced.

3.3 Data collection for the relocation process

To gather data of the process and assess the feasibility of relocating the case study building, an investigation was conducted through interviews and correspondence with Tunga Lyft, a relocation company. The primary objective of the interviews was to procure comprehensive information regarding the machinery and equipment encompassed in the relocation process considering machine hours and transportation distances. Suggestions to determine the extent of the case study building that could be relocated and the new material that was required for the new site of the relocation.

3.4 OneClick LCA

The software OneClick LCA (OCL) is used for assessing the LCA compliance with EN 15987 as it considers all mandatory stages within the LCA. The database of Environmental product declarations (EPD) within the software is integrated with multiple EPD platforms globally which generate EPDs from various manufacturers on the basis that they fulfil the requirements of quality and validation through the standardized procedure of 14025 (Environmental Labels and Declarations type III) (One Click LCA, n.d.). The materials were quantified in Revit combined with Excel and within the OCL the materials were assessed considering the processes involved in the relocation and the complete demolition for the two cases. Furthermore, all machinery and transports used for the different processes connected to the relocation are also calculated within the software considering the data received from interviews with Tunga Lyft. For module C1 in the End-of-life hand-calculation was conducted from the EPDs since this cannot be obtained from OCL.

3.5 LCA

The two different cases assessed were used to estimate the difference in GWP if the case building was relocated (Case A) or if the case building was demolished and replaced by a new one with the same gross floor area as the case building (Case B).

Goal and scope
The purpose of the LCA is to assess the potential climate impact (kg CO_2e) generated when relocating an existing building to a new building site based on a case study (Case A). The assessment includes the processes and preparation that occur when relocating a one dwelling building from point A to B. In addition to that is the construction work once the building has reached its destination. The comparison will consider that if the relocation of the building cannot happen then a new construction of a building must take place and the existing building must be demolished (Case B). The study aims to perform research on the possible environmental benefits of relocating a building and potentially saving the embodied GWP in buildings.

The functional unit used in this study was kg CO_2e / m^2 BTA of the one-dwelling building that provides weather sheltering and a heated space.

Calculation period: The process when the buildings are finalized and ready to function.

System boundaries
The system boundaries addressed in this LCA follow the standard of EN 15978. The life cycle stages considered in this study were A1 – A3 (Product stage), A4 – A5 (Construction stage), B6 (Use stage) and lastly C1 – C4 (End of life stage). Selected LCA modules are presented in Figure 5.

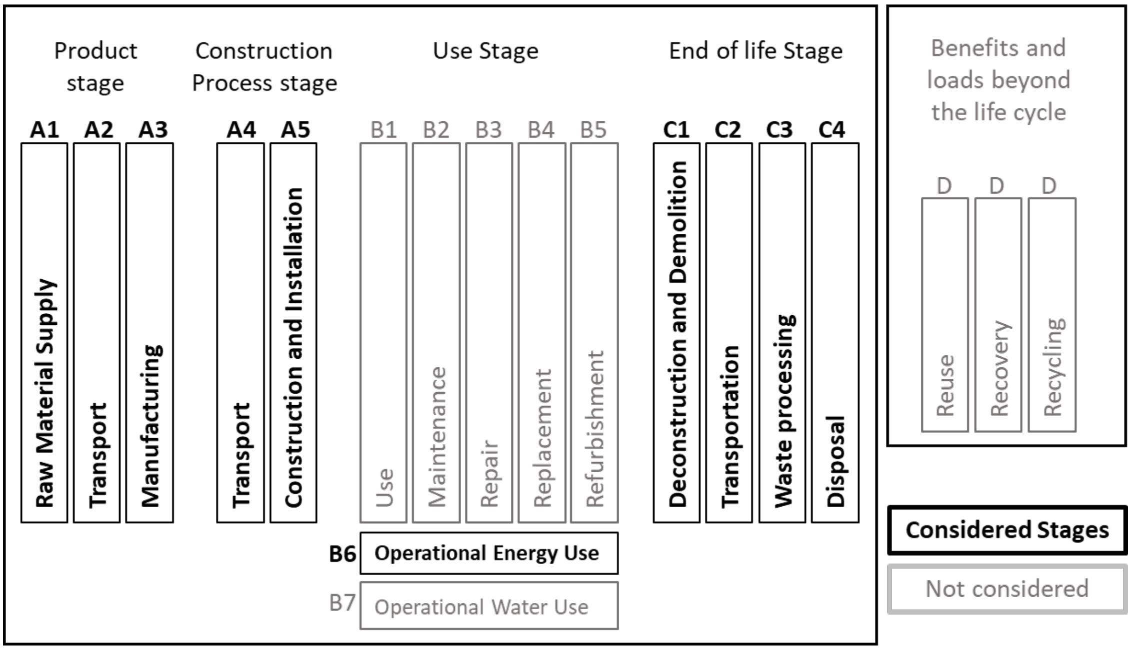

Figure 5 Life cycle stages considered in the study, in accordance with EN 15978

Presented in Table 9 and Table 10 is the respective processes and sources used in this study to assess the impacts of the different cases.

Table 9 Data required for the LCA of Case A

Module	***Processes causing impact (Case A)***	***Source***
A1 - A3	The new material that is required to be produced for the new site.	(Boverket, 2023a)
A4	Transportations involved in the relocation of the building and additional materials to the new site.	Tunga Lyft (Boverket, 2023a)
A5	Required work at the original site. Required construction work at the new site.	Tunga Lyft (Malmqvist et al., 2021) (Boverket, 2023a)
B6	The energy required for heating and domestic hot water use. Emission factor for district heating.	(Energiföretagen Sverige, 2022) (Energimyndigheten, 2022)
C1 - C4	Demolition process for the partial demolishment.	EPD generated through OCL.

Table 10 Data required for the LCA of Case B

Module	***Processes causing impact (Case B)***	***Source***
A1 - A3	New materials that are required to be produced for the newly constructed building.	(Malmqvist et al., 2021)
A4	Transportation involved for the new material required for the newly constructed buildings.	(Malmqvist et al., 2021)
A5	Required construction work for the new building.	(Malmqvist et al., 2021)
B6	The energy required for heating and domestic hot water use. Emission factor for district heating.	(Energiföretagen Sverige, 2022) (Energimyndigheten, 2022)
C1 - C4	Demolition process for the demolishment.	EPD generated through OCL.

It was prioritised that EPDs that were selected should declare the End-of-life stage for all modules C1 – C4 of LCA calculations. In this study the C-module corresponds to the demolition part of the original site therefore, it should be noted that once the case study building is relocated or the new building (reference building) is constructed, the EoL is not considered. Regarding the EoL for the two scenarios is dealt with in the same way but differs in the amount of building elements which is demolished. As stated in Case A is potentially partially demolished compared to Case B where the entire case study building is. The selection process for EPDs available in OneClick LCA is based on specific criteria as seen below.

- *Similarities of existing material and existing EPDs in terms of material properties and function.*
- *Stage C where all modules shall be declared.*
- *Nationality source, primarily Sweden but can be based in any other EU country.*

In the case of the multiple EPDs fulfilling all the criteria for material, an evaluation of the impacts in the respective module was considered. If there is a major difference in the results the more "conservative" EPD was selected.

LCA limitations
The main objective of this report was to investigate the complete process involved in relocating a building constructed in the 1950s compared to constructing a new building and demolishing the case study building. Due to the gap in information regarding the subject, the study has uncovered certain assumptions and limitations listed below.

- Evaluation of category impacts is limited to GWP.
- Selection of EPDs
- Inaccessibility of machinery for the relocation process in OCL.
- Assumptions of distances of transportation for machinery connected to the relocation.
- Required construction work at the relocated site.
- Actual energy use of the buildings for space heating and domestic hot water use.

3.6 Considering the potential environmental benefits of relocation of a building

The standard EN 15978 guidelines for calculations of reusing building materials have not been developed hence in this study the potential benefits of reusing material are based on IVL calculation on how to consider reuse material. However, it is stated that these guidelines are primarily an interpretation of the standard and a proposal for how calculations can be conducted (Gerhardsson et al., 2020b). The evaluation of the result is conducted through a comparison of the reuse scenario compared to a linear scenario based on the nomenclature presented by IVL. For this study, the reuse scenario is Case A, and the linear scenario is Case B. Included in the reuse scenario is described in Equation 1.

Equation 1 Climate impact of reuse

$$Scenario_{reuse} = M_{transportation} + M_{intermediate\ storing} + M_{reconditiong} + M_{build-in}$$

Below the different variables from IVL will be described for what is included in the calculation in Table 11.

Table 11 Parameters involved in the calculation of the scenario reuse.

Variable	Included
$M_{transportation}$	- *What type of vehicle is used and the type of fuel.* - *How far is the material transported.* - *How many products are contained for the transportation*
$M_{intermediate\ storing}$	- *The energy use of the warehouse* - *The time the products are stored.* - *The amount of space that the material takes.*

$M_{reconditiong}$	- *How much new material and what type is supplied to fulfil the previous function.* - *What are the potential emissions from this*
$M_{build-in}$	- *The amount of work necessary to build in reused material are equivalent to the work to build in new material.*

For this study, there is no intermediate storing as the case study building is directly relocated to its new location hence this variable is excluded from the Equation 1. Regarding the reconditioning of the building elements, an assumption is based on the interview conducted with the relocation company.

The linear scenario is when the case study building is demolished, and new construction is built presented in Table 12. The outcome of waste treatment and transportation is considered through EPD:s from OneClick LCA, however for the newly constructed building a reference value will be used to compare the environmental impact for the two scenarios. The calculation for the linear scenario is covered in Equation 2.

Equation 2 Climate impact of the linear scenario

$$Scenario_{linear} = \left(M_{waste\ treatment} + M_{transportation}\right) + (M_{new\ production} + M_{transportation})$$

Table 12 Parameters involved in the calculation of the scenario linear

Variable	Included
$M_{waste\ treatment}$	- *Demolition and deconstructing of the building.* - *Handling of residual waste and disposal*
$M_{transportation}$	- *What type of vehicle is used and the type of fuel.* - *How far is the material transported.* - *How many products are contained for transportation.* - *Includes both new and existing material*
$M_{new\ production}$	- *Production of material* - *Raw mineral supply*

The interpretation of the calculation will be assessing Case A as mentioned will correspond to the scenario of reuse with a slight modification since it will also consider the potential waste treatment which might occur in the relocation process compared to Case B, the linear scenario. Assessing the environmental benefits of the reuse scenario, IVLs calculation for climate savings will be used before the implementation of the B6 module. Expressed in Equation 3 is the calculation for potential climate savings.

Equation 3 Climate savings comparing the two scenarios

$$Climate\ savings = \ Scenario_{linear} - Scenario_{reuse}$$

Further, the LCA was conducted as described in chapter 3.3 where the implementation of the B6-module will be introduced. The comparisons are divided into different steps to be able to see the potential impact of the use of energy, this since the two compared building has a major difference in terms of energy demand.

3.7 Methodology of the analysis

To further investigate the two cases, analyses was undertaken to address potential uncertainties in the results and explore the effects of testing various parameters that influence the outcomes. The analyses aimed to mitigate any ambiguities and enhance the understanding of the findings. The analyses that were conducted are listed below.

- Impact of transportation depending on the geographical location
- Impacts of varying calculation methods for transportation
- Dependency of the operational energy use
- Prevented GWP in case of reuse

Impacts of transportation depending on the geographical location

To evaluate the influence of transportation in Case A, the investigation involved exploring different geographical locations for the proposed new site, specifically Stockholm or Malmö. By altering the location of the new building site, the distances involved in transporting the case study building would vary accordingly and change the outcome. In contrast, Case B was not affected by these variations in distances, as the construction of the new building, in this case, was based on a predetermined reference value for one or two occupancy dwellings. The different geographical location will also affect the determining emissions factors for district heating as this varies depending on location.

Impacts of varying calculation methods for transportation

In addition to varying the different distances of transportation for Case A, different calculation methods for transportation were utilised for the transportation of relocated building. To address how the results might differ depending on which approach that is utilised. The methods compared are:

- *Transported mass*, based on the amount of weight carried by the vehicle and the type of vehicle combined with the distance calculated in OneClick LCA software.

- *Fuel based*, utilizing the Trafikverket's database to determine the type of vehicle and its corresponding fuel consumption. Using the calculated diesel consumption, the carbon emissions were then estimated using the emission factor for diesel within the OneClick LCA software (Trafikverket, 2022).

- *Tank to wheel (TTW) and Well to wheels (WTW),* TTW The TTW perspective focuses on the direct emissions that occur when the fuel is consumed by the vehicle, taking into account the emissions during operation. WTW perspective considers the life cycle of the fuel, including extraction, production, and distribution processes, in addition to the emissions from vehicle operation. Both TTW and WTW assessments relied solely on the values provided by Trafikverket for the specific vehicle types involved in the analysis. This approach ensured a comprehensive evaluation of emissions from different stages of the fuel life cycle and their impact on the overall carbon footprint (Trafikverket, 2022).

Dependency of the operational energy use

The energy use for space heating and domestic hot water is determining the outcomes of module B6 for the cases and is assessed once the two cases are operating. To assess the impact of energy use, the energy use for Case A varied, while Case B maintained a constant energy use. By comparing the two cases with varying energy use for Case A but consistent energy use for Case B, the effects of different energy usage scenarios could be evaluated. The overall results and outcomes of module B6 will be expressed in an environmental payback time.

Prevented GWP in case of reuse

In this study, the LCA did not include the D-module. However, to assess the potential environmental benefits of relocating buildings, an evaluation was conducted by calculating GWP emissions that would have been generated if the saved materials from Case A were newly produced. The savings resulting from the reuse of materials were determined by calculating the emissions associated with the product stage (A1 - A3) using EPDs for each specific material being transported to the new location in Case A. These emissions were interpreted as prevented emissions due to the reuse of materials, representing the environmental benefits achieved through the relocation process expressed in kg CO_2e.

4 Results

The results will be presented in the order in which the study was carried out. Initially, a literature study was conducted to provide a understanding of the existing research connected to the study presented in Chapter 2. The case study building was modelled, and the building materials were quantified. The building materials were matched with EPDs according to the requirements set in 3.3 enabling an evaluation of the End of life stage for the two different cases. The establishment of methods considering the LCA of the two cases are based on the conducted interview with Tunga Lyft. Finalizing the results of relocation with new materials and construction work to fulfil the function of the building the completing the LCA for Case A. An overview of the LCA results connected to Case B with the impact occurring for the demolition of the entire case building and the construction of the reference building. A comparison of the cases before the implementation of the operational energy use, B6, will be conducted. This will be followed by a study focusing on B6 and with a variation of the climate impact from the district heating used as an energy source. Lastly, an analysis of uncertain parameters is conducted. The outline of the result section is presented in Figure 6.

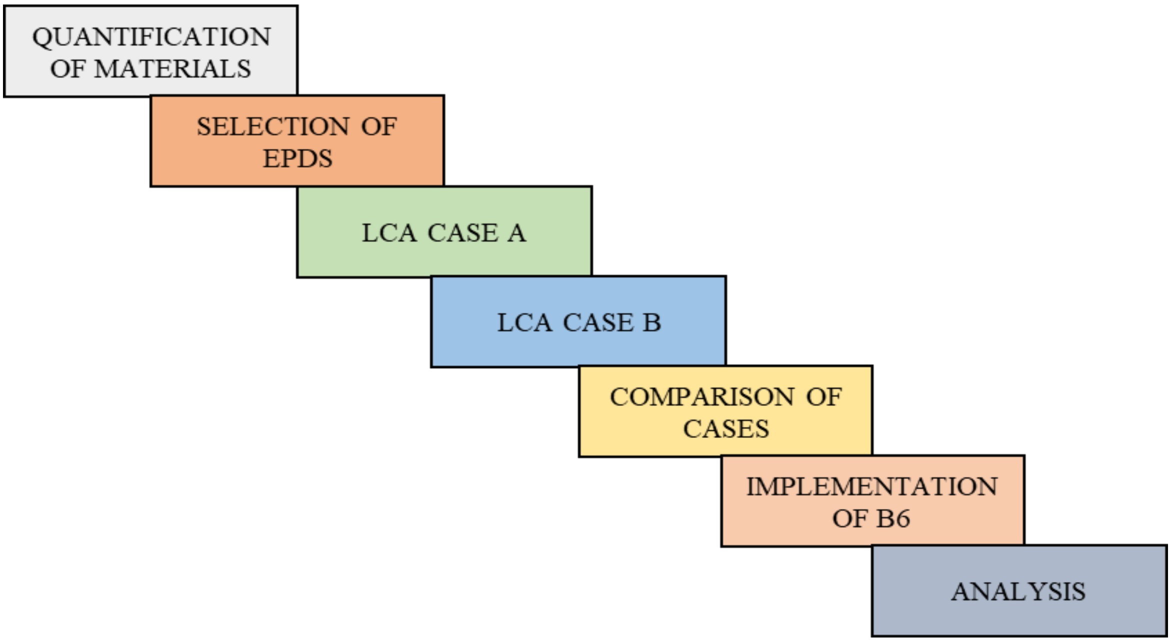

Figure 6 Description of the outline of the results

4.1 Quantified Building Materials

Calculated quantities for the respective materials in the case study building, was received from a 3D model that was modelled in Revit. For components of the building that lacked information, designs were adopted based on equivalent solutions. These components are presented in Table 13. The final model is presented in Figure 7.

Table 13 Building components where assumptions were implemented during the design

Building Element	Component	Source
Foundation	Concrete plates	(Mårdberg, 1996)
Foundation, Main floor joist	Reinforced steel bars	(Stena Stål AB, n.d.).
Facades finishing	Plaster	(Bodin et al., 2016).
Attic and Roof	Wooden trusses	(Bodin et al., 2016; Burström, 2007).
Additional building elements	Wooden porch	(Svenskt Trä, n.d.)

Figure 7 Model of case study building in Revit.

The results from the quantification of the materials with corresponding weights are presented in Table 14, showing a total weight of approximately 170 tons for the whole building. Most of the weight can be linked to three concrete based materials that appear in the building's basement, intermediate floor, and walls, having a combined weight of 133 tons. Plaster, which is used in the exterior and interior façade finish accounts for approximately 14 tons of the total weight.

Table 14 Materials used in the case study building.

Material	**Complete building (tons)**
Concrete	88,32
Lightweight Concrete	30,86
Concrete Masonry Unit	14,09
Plaster	13,75
Wood	8,18
Masonry Bricks	4,63
Coke ash (insulation)	2,78
Steel	2,61
Windows	1,31
Gypsum	1,25
Wood Fibre Insulation Board	0,99
Doors	0,55
Tiles	0,38
Loose wood fibre insulation	0,30
Natural stone	0,28
Plastic	0,25
Substrate paper	0,16
Particle Board	0,02
Total mass	**170,69**

4.1.1 Quantities in the relocated part of the building

During the interview, it was specified which parts of the building were appropriate to include in the relocation. This resulted in the assumption that the main floor and the attic would be included in the move. Other parts of the building, such as the basement with the complementary garage and the south-facing veranda, were not included in the relocation due to factors that would complicate the relocation process. Since the building was designed with a basement floor, the appropriate option was to split the building into two parts: One part that will be relocated and one part that will not be relocated.

Based on this information, the quantities presented in Table 14 was divided into materials to be relocated and material not to be part of the relocation and thus demolished. To enable the move, a lifting construction was required to be mounted under the building. This construction consisted of steel beams that were mounted below the building's main floor and along the lower edge of the facade.

In this case, the process consisted of drilling holes in the upper part of the basement wall and then mounting the beams under the main floor joist. Figure 8 presents a model of the building suitable to be transported with the additional steel beam construction. As can be seen from the model, the steel beams are placed under and around the lower part of the building which was based on similar lifts performed by Tunga Lyft.

Figure 8 Model of the part of the building being relocated.

From the selected part of the building shown in Figure 8, further inventory was carried out to quantify weights for the materials that would later be transported. The results of quantified weights for the part of the building that will be relocated are presented in Table 15. The results show that the relocated materials measure a total weight of approximately 71 tons. Relocated materials with a weight of 0 tons indicates that the materials were used in parts of the building that would not be relocated. These materials are referred to as demolished materials and measure a total weight of 107 tons. The greatest difference between the weights was related to the reduction in concrete due to not including the basement in the relocation. Furthermore, this resulted in a reduction of the building's gross floor area (BTA) from 260 m^2 to 126 m^2 and the heated floor area of 186 m^2 to 93 m^2 referred as A_{temp}.

Table 15 Materials with weights to be relocated.

Material	**Complete building (tons)**	**Relocated materials (tons)**	**Demolished materials (tons)**
Concrete	88,3	12,0	76,3
Lightweight Concrete	30,9	27,6	3,2
Concrete Masonry Unit	14,1	0,0	14,1
Plaster	13,8	7,6	6,1
Wood	8,2	5,7	2,5
Masonry Bricks	4,6	1,6	3,0
Coke ash (insulation)	2,8	2,8	0,0
Steel	2,6	2,3	0,3
Windows	1,3	0,6	0,7
Gypsum	1,3	1,3	0,0
Wood Fibre Insulation Board	1,0	0,0	1,0
Doors	0,6	0,4	0,2
Tiles	0,4	0,4	0,0
Loose wood fibre insulation	0,3	0,3	0,0
Natural stone	0,3	0,3	0,0
Plastic	0,3	0,0	0,3
Substrate paper	0,2	0,1	0,0
Particle Board	0,0	0,0	0,0
Additional materials			
Steel beams	0,0	8,2	0,0
Total mass	**170,7**	**71,3**	**107,6**

4.2 Selection of EPDs

After the case study building was inventoried and the quantities of all the materials have been calculated followed the process of selecting EPDs in chapter 3.3. The results of the selected EPDs were based on the database in OneClick LCA and are presented in Appendix A.

4.3 Establishment of method for Case A

Additional results from the interview examined which processes that would be comprised in a relocation of the case study building, further described as Case A. Information obtained from the interview was to identify activities related to the entire sequence of events, as well as to gather information related to specific stages. As a result, a process timeline was created, shown in Table 16 and Figure 9.

The first step in Case A involves the transportation of equipment, machinery, and personnel to the original site in Åre, Sweden. The transportation was based on distances from the office in Stockholm and warehouse in Motala of Tunga Lyft to the building site in Åre. The beams required to create a provisional foundation to manage the lifting of the frame were transported from the warehouse. The next steps would cover the preparatory work at the building site with machinery transported from local manufacturers and the mobile crane from the office in Stockholm. The adjacent ground is excavated to create appropriate conditions for the following step of mounting the lifting frame. The frame is assembled with a mobile crane. When this step is complete, the building can be lifted onto a truck which is then transported to the new building site. As the part of the building that will be relocated is removed from the original building site, the remaining building construction can be demolished.

For the building to be placed on a new site, a new foundation must be constructed. This requires excavation work prior to the casting of the foundation. When the new foundation is finished, the building can be installed on the new site. Finally, the building's facades need to be replastered because of potential cracks in the lifting and transportation. After this step, the building can be put into use and equipment, machinery, and personnel transported back to their original location. All distances for each process are presented in Chapter 4.5.1.

Based on the interview, all processes involved in the house relocation were identified and organised according to each process's specific LCA module. The previously selected LCA modules described in Table 9 were applied, resulting in a method that divides processes according to their chronological order. The method, described in Table 16, consists of 8 segments covering the entire sequence of events. Results show that LCA modules for transportation (A4) and installation (A5) occur multiple times in the method. Figure 9 presents the schematic structure of Case A.

Table 16 Description of processes included in Case A

Segment	LCA-Module	Processes included in the relocation of the building (Case A)
1	A4.1	Transportation of materials, equipment, machinery, and workers to the existing building site
2	A5	Preparatory work prior to the transportation of the building
3	A4.2	Transportation to the new building site
4	C1 – C4	Demolition of the remaining construction on the existing site
5	A1 – A5 (Incl. A4.3)	The casting of the foundation and additional plaster for the external facade at the new building site
6	A5	Installation of the building at the new building site
7	A4.4	Transportation of materials, equipment, machinery, and workers back to each original location.
8	B6	The move is complete, and the building is put into use

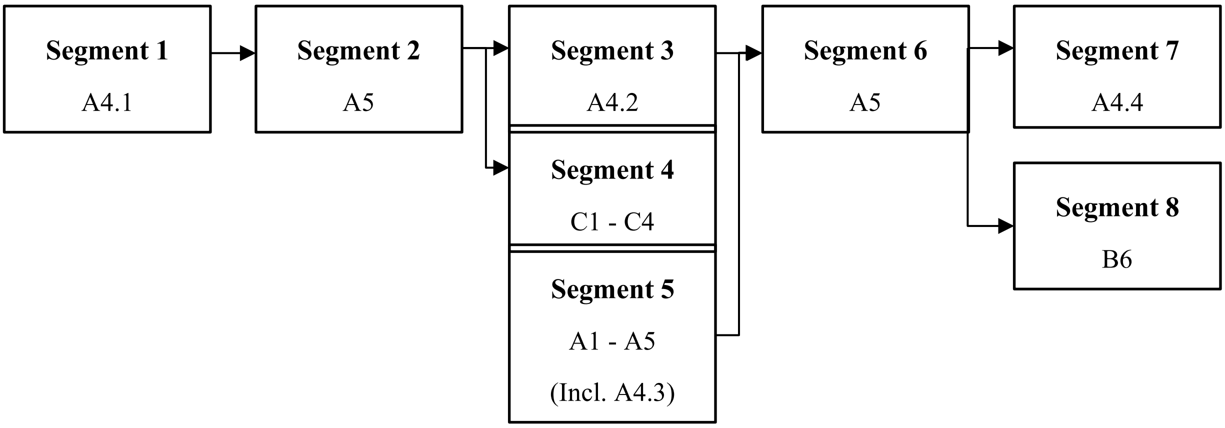

Figure 9 Schematic Structure of Case A divided into segments

4.4 Establishment of the method for Case B

From the LCA modules described in Table 10, a schematic structure was designed for the case in chronological order according to when the activities occur. Results of this schematic structure with a description of the LCA calculation of Case B are presented in Table 17 and in Figure 10.

Table 17 Description of processes included in Case B

Segment	LCA-Module	Processes included in Case B
1	C1 – C4	Complete demolition of case study building
2	A1 – A5	Construction of a new building at a new site
3	B6	The building is put into use

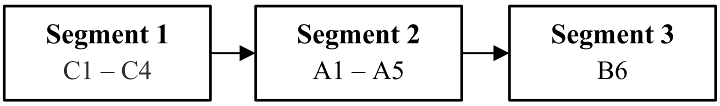

Figure 10 Schematic structure of Case B

4.5 LCA results Case A

The modules declared for the LCA of Case A are presented in Figure 11 apart from B6 which will be further discussed in Chapter 4.8. The results of the LCA for Case A will be presented for the entire relocation procedure, for each module, allowing for a more detailed understanding of the individual processes that impact the overall environmental performance of the building. For the complete process of relocating the building was transported from the original site to a new location 10 km away. The outcomes derived from the outcome of OneClick LCA indicate that the major contributors to the LCA of the building are concentrated in stages A1 - A5, which correspond to the procurement of new materials, transports for relocation and construction activities at the new and the original site of the building. Specifically, A5-module is the highest contributor in Case A. Conversely, the impact resulting from other modules, the partial demolition (C1 - C4) is relatively minor.

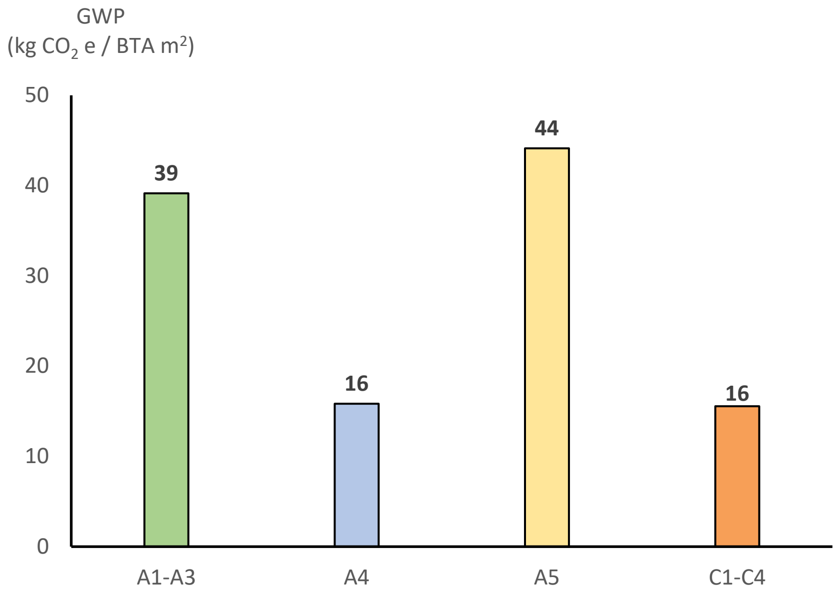

Figure 11 Impacts of the declared modules excluding B6 for Case A

4.5.1 A4: Transportation

Regarding the A4 module, the results shown in Figure 12 are based on the various types of transportation required to facilitate the relocation process based on the conducted interview with Tunga Lyft in Chapter 4.3.1. The input data used in OneClick LCA for the different transportation is presented in Table 18 for each process, the type of vehicle used, including the transported mass, distance, and emission factor. The distances were designed to account for transports to the site and back to their original location, e.g. the transport of the beams consists of 700 km to the construction site and 700 km back to the warehouse. The transport of building material for the foundation and plaster is based on generic data from Boverket database in OCL obtaining the distance and the type of vehicle whereas the other transportation is based on the conducted interviews with Tunga Lyft. Transportation of machinery from local manufacturers is the excavator (Terex TW110) and wheel loader (L90) which are required for the preparatory work at the site whereas the mobile crane (Maeda815) is transported from the office in Stockholm. The beams are transported from the warehouse in Motala. The hydraulic pumps are included in the transportation of the mobile crane.

Table 18 A4 is divided by linked processes.

Process	Stage	Type of vehicle from OCL	Weight (tons)	Total distances (km)	Emissions factor (kg CO_2e / tonkm)
Transport of the whole building	A4.2	Trailer combination, 40-ton capacity, 100% fill rate	71	10	0.04
Transport of beams	A4.1, A4.4	Trailer combination, 40-ton capacity, 50% fill rate	8.2	1 400	0.05
Transport of Terex TW110	A4.1, A4.4	Trailer combination, 40-ton capacity, 100% fill rate	12.5	20	0.04
Transport of L90	A4.1, A4.4	Trailer combination, 40-ton capacity, 100% fill rate	16	20	0.04
Transport of Maeda815	A4.1, A4.4	Trailer combination, 40-ton capacity, 100% fill rate	9.7	1 200	0.04
Transport of personnel	A4.1, A4.4	Delivery van, 1,2-ton capacity, 50 % fill rate	0.8	1 200	0.52
Transport of concrete to new site	A4.3	Lorry (1,5 MJ/ton km). Swedish reduction diesel mix	30	35	0.11
Transport of reinforcement to the new site	A4.3	Lorry (1 MJ/ton km). Swedish reduction diesel mix	1.3	1 040	0.08
Transport of insulation to the new site	A4.3	Lorry (1 MJ/ton km). Swedish reduction diesel mix	0.4	440	0.08
Transport of plaster to the new site	A4.3	Lorry (1 MJ/ton km). Swedish reduction diesel mix	1.5	440	0.08

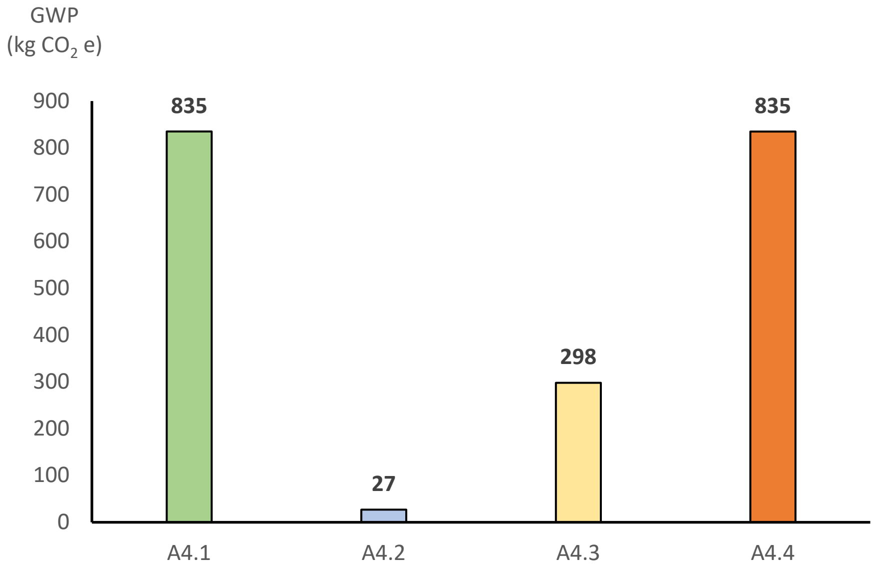

Figure 12 Impact of transportation in the partial demolition

Based on the results presented in Figure 12 the amount of impact for the different transportation required is listed in Table 19, the impact of transporting the building considered as A4.2 is relatively low compared to the impact of other processes involved in the building's relocation. A4.1 and A4.4 have a similar impact since the same processes are involved with equal distances and note that there is no intermediate storage of the vehicle during transportation.

Table 19 Impacts in A4 for Case A

Stage	Impact per process (kg CO_2 e)	Total Impact (kg CO_2 e)
A4.1	Transport of beams = 280	835
	Transport of Terex TW110 = 5	
	Transport of L90 = 6	
	Transport of Maeda815 = 241	
	Transport of personnel = 303	
A4.2	Transport of relocating of building	27
A4.3	Transport of concrete = 117	298
	Transport of reinforcement = 100	
	Transport of insulation = 14	
	Transport of plaster = 67	
A4.4	Transport of beams = 280	835
	Transport of Terex TW110 = 5	
	Transport of L90 = 6	
	Transport of Maeda815 = 241	
	Transport of personnel = 303	
Total (A4)		1 995

4.5.2 A5: Construction and installation

The A5 considers the utilisation of machinery before and after relocation during the construction phase, with consideration of working hours from the interview conducted with Tunga Lyft chapter 4.3.1, combined with the OneClick LCA database of machinery. The selection of machinery for each process is presented in Table 20.

Table 20 Processes involved in A5 for Case A

Process	Actual machine	Machine (OCL)	Effective hours (h)	kg CO_2e / h
General construction work	L90	Wheel loaders, diesel-driven, operation per hour, average power: 94kW, loading factor: 33%	24	29.94
Installation of beams beneath the house	Maeda815	Crane, diesel-driven, operation per hour, average power: 99kW, loading factor: 26%	32	24.22
Piercing through the envelope, creating holes in the beams	-	Other hand-operated machinery, petrol-driven, operation per hour, average power: 1 kW, loading factor: 40%	40	0.69
General groundwork, creating better access	Terex TW110	Excavator, wheeled, diesel-driven, operation per hour, average power: 88kW, loading factor: 32%	90	26.78
		Electric use (kWh)	Effective hours (h)	CO_2e / kWh
First lift off for the house	Hydraulic pump	4.7	12	0.04

A5.1 waste generated at the new site for the new material is based on the generic values of Boverket database in OCL is listed in Table 21 as well as the standard value for construction work at the new site from IVL described in the 2.2.2 (Malmqvist et al., 2021). The amount of material for the foundation which includes the insulation, concrete and steel bars are based on the report scaled to match the gross floor area of the case study building of 126 m^2 (Dahlgren et al., 2021).

Table 21 Values used in the calculations in A5

Building material required at the new site	**Amount**
EPS, expanded polystyrene, pressure class 80	403 kg
Steel rebar, unprocessed, 100 % scrap based, excl. alloying elements, 7850 kg/m3	1 260 kg
Ready-mix made concrete, climate improved, C30/37, 2350 kg/m3	13 m^3
Masonry mortar and plastering type B (CS III), 1600 kg/m3	121 m^2
IVL	
The standard value for general construction work	10.8 kg CO_2e/ m^2 BTA

The outcomes of A5 for Case A are illustrated in Figure 13, demonstrating the effects of the various involved procedures. The influence of the different processes where the heavy machinery was involved dominates the total climate impact, whereas processes considering smaller machinery are almost neglectable compared to this. The heavier machinery process is predominantly linked to the number of hours and the emissions factors involved.

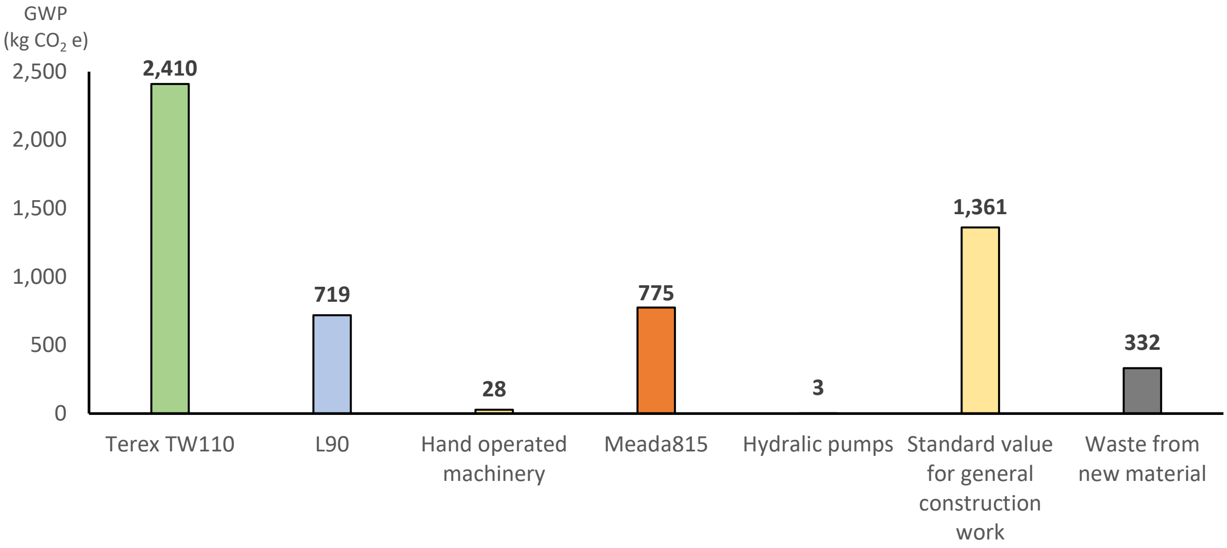

Figure 13 Impact of the relocation preparation and construction at the new site

4.5.3 C1 - C4: End of life stage

Results presented in Figure 14, are the resulting impact of the partial demolition that occur for the case study building gathered from Table 15. The construction parts are divided up into categories according to the OneClick LCA layout, a more detailed description of what type of material each category contain is presented in Appendix A. The primary source of greenhouse gas emissions resulting from the partial demolition is predominantly attributed to the quantity of concrete present in the basement.

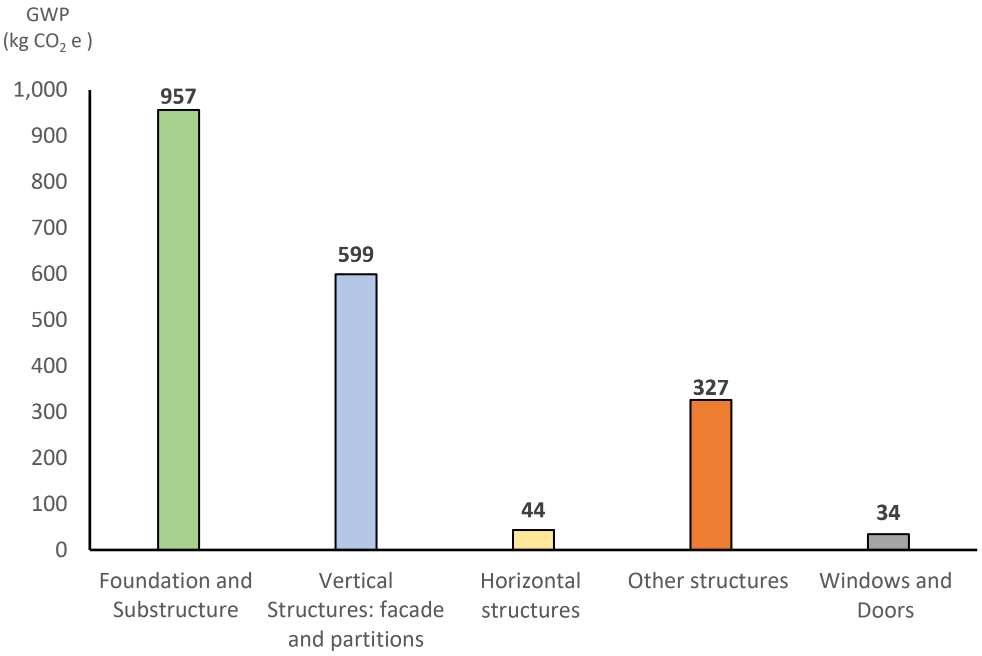

Figure 14 Impact of the End of Life for Case A

For each category, the contribution to the EoL-stage and the material with the highest impact is listed in Table 22. The concrete in the foundation and the partition walls made of wood in the basement are the two main contributing materials for the category's *foundation and substructures* and the *vertical structures* which are the highest contributing categories. *Other structures* which encompass the porch slated are identified as one of the highest emitters of greenhouse gas emissions, primarily due to its size which accounts for 17% of the total EoL-stage.

Table 22 Distribution of impact of the different categories

Category	Percentage of the total demolition (%)	Highest contributing material
Foundation and substructures	49	Ready-mix concrete, C35/45, XD1, XS1, XS2, XF2, XF3, XA2, 2 250 kg/m^3
Vertical structures: façade and partitions	31	Interior wood cladding with surface treatment from pine, 500 kg/m^3, 14x120 mm, 8.92 m of wood cladding/m^2, 10% moisture
Horizontal structures: roofs and floors	2	External wood cladding with surface treatment from spruce, 464 kg/m^3, 19x145 mm, 7.69 m of wood cladding/m^2, 16% moisture
Other structures	17	External wood cladding with surface treatment from spruce, 464 kg/m^3, 19x145 mm, 7.69 m of wood cladding/m^2, 16% moisture
Windows and doors	1	Fixed window with wooden frame and aluminium cladding, triple glazed, per unit, U-value = 1.0 W/m^{2}K

Figure 15 presents the outcomes of the various modules within the end-of-life stage, where the processing of waste for reuse, recovery, and recycling (C3) is shown to be the most significant contributor followed by C1, C2 and lastly C4. The assessment of the resulting impact of C1 is accomplished through manual calculation, utilizing either the functional unit or the declared unit as presented in the corresponding EPDs, as this is not addressed in the results generated by the OneClick LCA software.

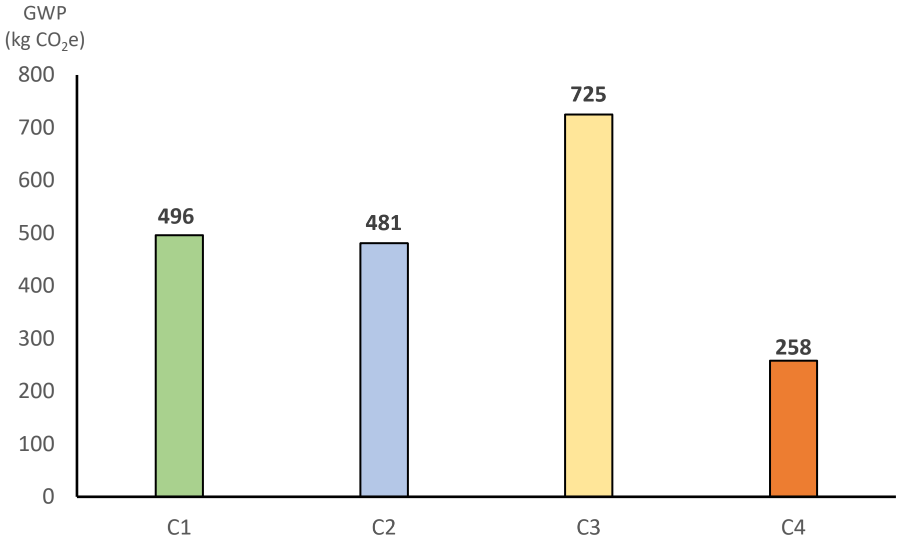

Figure 15 Impact of each module in End of Life for Case A

4.5.4 A1 - A3: Product stage

The construction material required for the new site involves the casting of the foundation and reconditioning of the façade using plaster material based on the conducted interview with Tunga Lyft. The materials for A1-A3 modules are depicted in Figure 16 which is listed in Table 23 for the amounts and emission factors. After the relocation, the only major part that was reconditioned was the façade due to the potential cracks that most probably would occur during the transfer and due to forces that the building would endure during the lift. Concrete is predominantly the highest contributor to the climate impact as presented in Figure 16. Climate-improved concrete was chosen for the new site since it was a possible option. For material necessary for the new foundation, it was scaled based on a previous report (Dahlgren et al., 2021).

Table 23 New material required at the new site

Generic product	Amount	Emission factor (CO_2e / kg)
Ready-mix made concrete, climate improved, C30/37, 2350 kg/m3	12.6 m^3	0.11
Steel rebar, unprocessed, 100 % scrap based, excl. alloying elements, 7850 kg/m3	1 260 kg	0.75
EPS, expanded polystyrene, pressure class 80	403 kg	4.0
Masonry mortar and plastering type B (CS III), 1600 kg/m3	1 936 kg	0.21

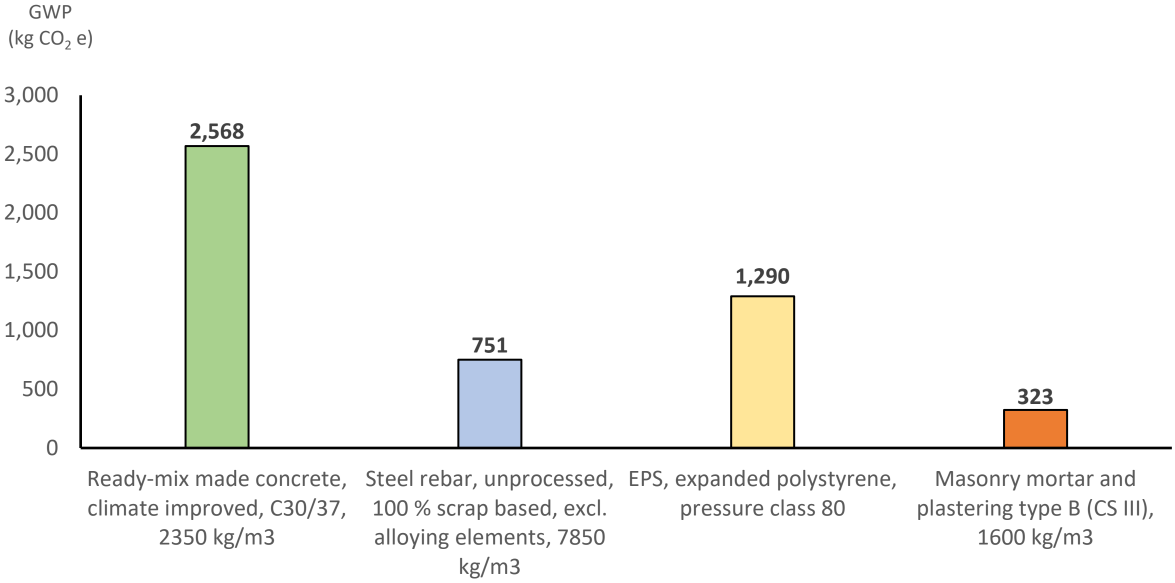

Figure 16 Greenhouse gas emissions from the new material

4.6 LCA results for Case B

A breakdown of the results from Case B is presented in the following chapter. The results are presented in parts, covering the complete demolition of the case study building and the construction of the new building. Values for the reference building were obtained from the study of for one- and two-dwelling houses (Malmqvist et al., 2021). In this study, the mean value of the climate impact of the new building was chosen based on the 2027 climate declaration with climate-improved values, as presented in Table 24. To adapt the construction of reference building to the case study building that is relocated in Case A, the standard values for ventilation, heating, and sanitation was therefore excluded from the calculation, shown in Table 8. The purpose of this exclusion is to ensure that the two cases have the same circumstances for heating of the building and energy required for hot water use.

The result of the total LCA of Case B as presented in Figure 17 with the complete demolition of the case study building shows a climate impact of 208 kg CO_2e / m^2 BTA, where the EoL stage corresponds to 59 kg CO_2e / m^2 BTA. A full description of the climate impact divided in different modules will be presented in the following chapters.

Table 24 GWP for stages A1 - A5 in the reference case

Reference case	**A1 – A3** (kg CO_2e / m^2 BTA)	**A4 – A5** (kg CO_2e / m^2 BTA)	**A1 – A5** (kg CO_2e / m^2 BTA)
One- and two-dwelling houses, mean value[1]	123	26	149

[1] The climate impact of the HVAC was removed from the reference building since the two buildings had two different types of systems.

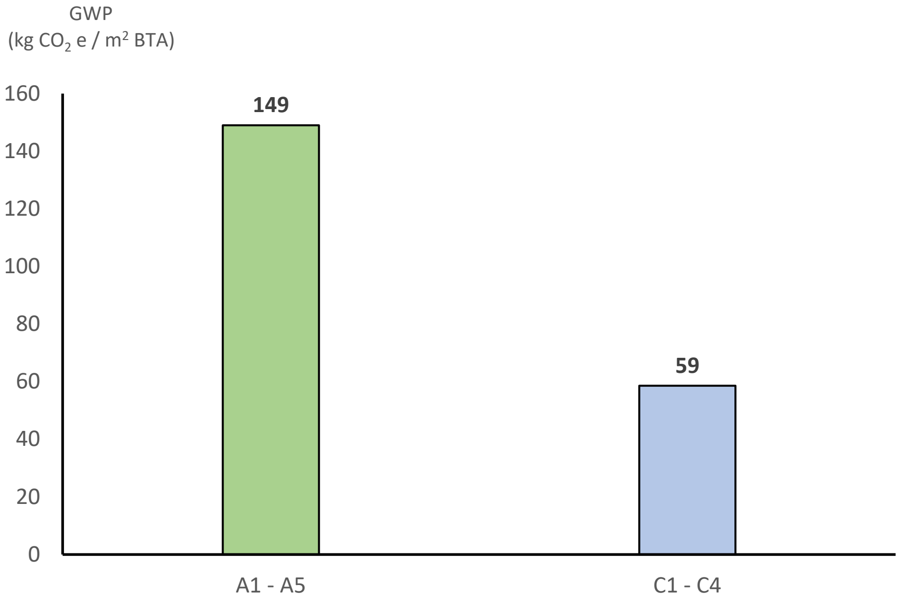

Figure 17 Impact of Case B for the declared stages excluding B6

4.6.1 C1 - C4: End of life stage

The result of the complete demolition of the case study building is depicted in Figure 18. The figure utilises the same categorization as for Case A, with a comprehensive description of these parts presented in the Appendix A. The results reveal that the total impact of the complete demolition is significantly larger than that of the partial demolition, where the construction category, *horizontal structures* contributed with the highest impact of 4 940 kg CO_2e.

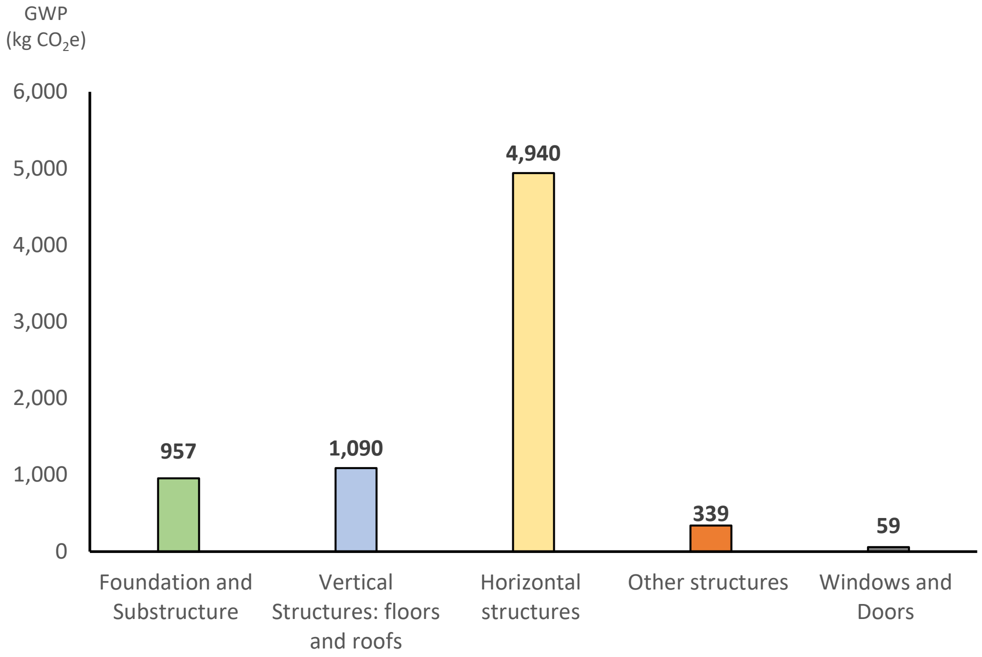

Figure 18 Impact of each category for the total demolition

Table 25 presents the main contributing material for the building, with variation of impact observed in each construction category. The highest contributor is within the category of horizontal structures, specifically the hardwood parquet floor on the first floor, followed by the interior wood cladding and the concrete.

Table 25 The percentage of impact from categories and the highest contributing material

Category	Percentage of the total demolition	Highest contributing material
Foundation and substructures	13	Ready-mix concrete, C35/45, XD1, XS1, XS2, XF2, XF3, XA2, 2 250 kg/m^3
Vertical structures: façade and partitions	15	Interior wood cladding with surface treatment from pine, 500 kg/m3, 14x120 mm, 8.92 m of wood cladding/m2, 10% moisture
Horizontal structures: roof and floors	67	Hardwood parquet flooring (oak), 22 mm x 129mm, B-2.0, 15.5 kg/m2, 725 kg/m3
Other structures	4	External wood cladding with surface treatment from spruce, 464 kg/m3, 19x145 mm, 7.69 m of wood cladding/m2, 16% moisture
Windows and doors	1	Fixed window with wooden frame and aluminium cladding, triple glazed, per unit, U-value = 1.0 W/m2K

As presented in Figure 19, the total result of the modules C1 - C4 corresponds to a climate impact of 7 383 kg CO_2e for the complete demolition in Case B . Module C3 shows to be the highest contributor of 4 510 kg CO_2e corresponding to approximately 60% in the EoL-stage. The type of management of waste has a significant impact on the C3 module's overall outcome. The other modules' impact compared to each other has a relatively similar result whereas C4 has the lowest contribution.

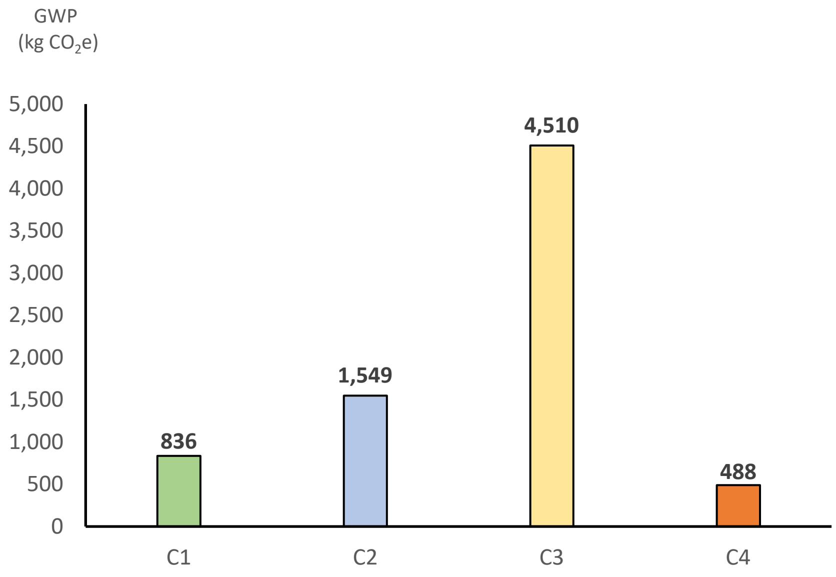

Figure 19 Impact of each module in End of Life in Case B

4.7 Comparison of scenarios before B6

The results of comparing the two scenarios are presented in Figure 20 where the case's outcome is when both buildings are finalized and ready to be used. The results indicate the biggest difference in the A1 - A3 stage between the cases. The processes involved in the relocation process A4 - A5 are the highest contributor for Case A whereas in Case B it is the lowest contributor. For Case B, the A1 - A3 is significantly higher than the rest of the modules where the EoL takes second place. In both cases, the product and construction stage (A1 - A5) correspond to the most influential impact in the LCA where the relocated building evens up to 70 % of the newly constructed building. For the EoL stage, Case A impact results to approximately 75 % compared to Case B.

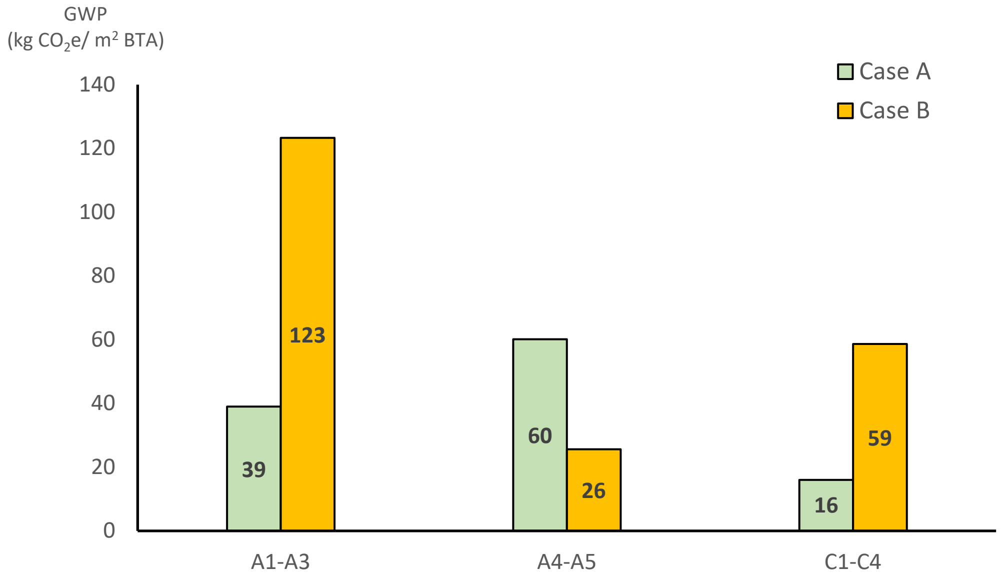

Figure 20, GWP divided in Life cycle stages for Case A and Case B

Considering the interpretation calculation of climate savings discussed in Chapter 3.4 the Equation 1 and Equation 2 are utilised for the climate impact (kg CO_2e / m^2 BTA) expressed below for Case A and B:

$$Case\ A: 16\ +\ 0\ + 39 + 60\ \ = 115\ kg\ CO_2e\ /\ m^2BTA \qquad \text{Equation 1}$$

$$Case\ B: 59\ +\ 123 + 26\ \ = 208\ kg\ CO_2e\ /\ \ m^2BTA \qquad \text{Equation 2}$$

As a result of the two calculations for the linear (Case B) and the reuse (Case A) scenario, the potential climate savings can be estimated through Equation 3.

$$208 - 115 = 93\ kg\ CO_2e\ /\ m^2BTA \qquad \text{Equation 3}$$

Resulting in a climate savings of 93 kg CO_2e / m^2 BTA where most savings occur since in Case A the required amount of new material necessary for the new site is significantly lower than in Case B.

4.8 Comparison after implementing B6

Presented in Figure 21 are the results of implementing the energy use for space heating and domestic hot water use for the two cases. The energy use is assessed when the building has been relocated in Åre for Case A and once the new building has been constructed in Case B. Case A exhibits a higher energy use of 119 kWh/m^2 in comparison to case B, which features an energy use of 74 kWh/m^2 that was based on the statistics of energy use for one- and two-dwellings (Energimyndigheten, 2022).

Considered for both cases are that they are connected to the district heating network and the heated floor area of the case study building will be used of 93 m^2. The greenhouse gas emissions from district heating are calculated with the Excel sheet provided by Energiföretagen to assess the impact of the building's energy use. Considering the emission factor of district heating it was calculated based on emissions from incineration, transportation, and production of fuels from Jämtkraft AB which is the closest energy distributor company of the case study building that utilises district heating at the new location (Energiföretagen, 2022). Furthermore, the emission factor was used to convert energy use into climate impact according to the following Equation 4 where the results are presented in Table 26.

Equation 4

$$GWP(kg\ CO_2e) = \frac{Emission\ factor \times Energy\ use}{1\ 000} = \frac{(g\ CO_2e/kWh) \times (kWh)}{1\ 000}$$

Table 26 Emissions occurring for district heating for the two cases

Cases	**Emission factor for district heating ($g\ CO_2\ e/\ kWh$)**	**Climate impact before B6 ($kg\ CO_2\ e$)**	**Emission based on the energy use ($kg\ CO_2e$ / year)**	**Payback-time (years)**
Case A	20	14 447	221	139
Case B	20	25 989	138	

The emissions factor associated with district heating is the determining factor of the outcome, in conjunction with the energy use required for the two cases depicted in Figure 21. The point at which the two approaches become "equal" is referred to as the break-even point, which occurs 139 years after the implementation of B6. In Case A, the annual increase in greenhouse gas emissions is equivalent to 221 kg CO_2e, while in Case B, it is 138 kg CO_2e.

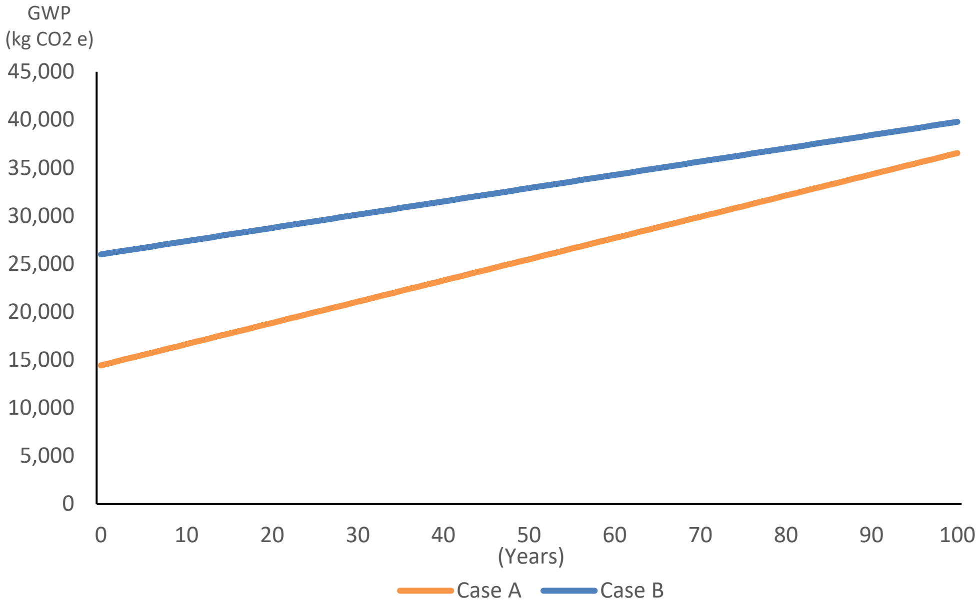

Figure 21 Initial climate impact as well as due to energy use (B6) over time for Case A and Case B with the new site located in Åre.

4.9 Analysis: Impact of transportation depending on the geographical location

To further investigate the impact of transport in Case A, an additional analysis was conducted by varying geographic locations for the new site. By changing the location of the new building site, the distances for the transports vary. In addition to Åre, Stockholm and Malmö were selected as intended locations for the relocated building. In this analysis, only the distance for the transport of the building in A4.2 is varied, indicating that the results for A4.1, A4.3 and A4.4 are constant for all cases. The scenario for Stockholm and Malmö as the location for the new site is presented in Figure 22.

Figure 22 Geographic location of Stockholm and Malmö

A compilation of the results of climate impact connected to transportation in three scenarios are presented in Figure 23. The stacked bar chart shows the results divided into the four stages of transport in A4.1 to A4.4, with the transported distance in A4.2 varying between the three scenarios. The results show that the increased distance related to the new sites indicates an increase in climate impact from the initial value with the new site located in Åre. As the transported distance in stage A4.2 increases from 10 km in the Åre-scenario up to 600 km respectively 1 100 km, the results in climate impact increase for Stockholm with 1 620 kg CO_2e and for Malmö with 2 943 kg CO_2e.

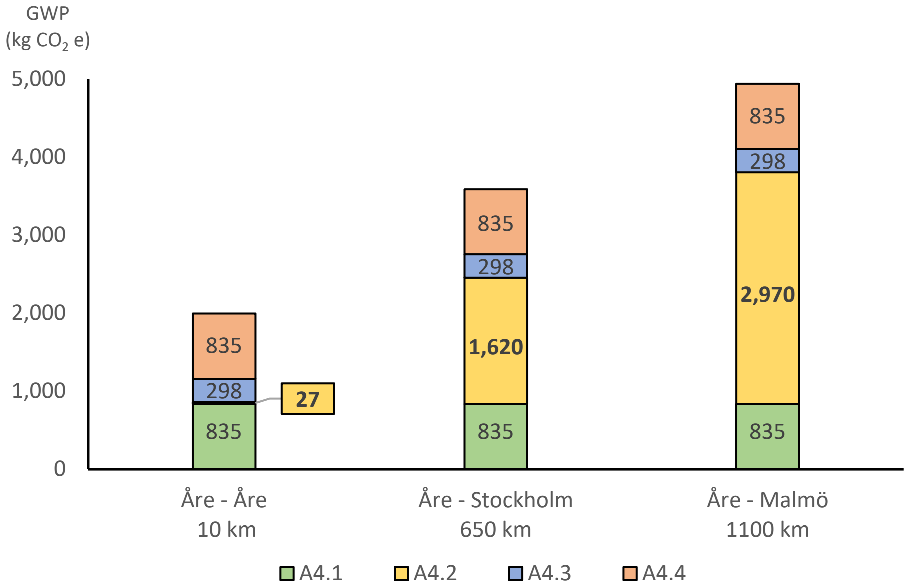

Figure 23 GWP for transport with different locations of the new site

Table 27 shows the total variation in climate impact for the different geographical locations selected for the new site. The result shows an increase in the cases of Stockholm and Malmö where the climate impact for A4 increases to 3 588 kg CO_2e and 4 938 kg CO_2e respectively. This results in an increase in the total climate impact that includes all transports (A4.1 – A4.4), described in Figure 23. In the Stockholm scenario, the climate impact for Case A increases by 1 593 kg CO_2e, resulting in a total climate impact of 16 040 kg CO_2e. In the Malmö Scenario, the climate impact for Case A increases by 2 943 kg CO_2e, resulting in a total climate impact of 17 390 kg CO_2e. Additionally, for the relocation to Malmö it is the first time where A4.2 exceeds an overall outcome that is major to all the other transports emissions combined.

Table 27 A4 with the difference in transported distance

New Site location	Distance (km)	climate impact A4.1 – A4.4 (kg CO_2e)	Total climate impact, excluding B6 (kg CO_2e)
Åre	10	1 995	14 447 (-)
Stockholm	600	3 588	16 040 (+1593)
Malmö	1 100	4 938	17 390 (+2943)

4.10 Impacts of varying calculation methods for A4

To further analyse how the results are dependent on transportation, different calculation approaches from the Trafikverkets database for average values for emission factors and fuel consumption for transport foreseen in 2030 for Case A was utilised (Trafikverket, 2022). The transportation of new material for the relocation is not considered and is kept the same as the Boverkets generic values as before. The three different calculation methods are listed below.

- *Transported mass*, based on the amount of weight carried by the vehicle and the type of vehicle calculated in OCL as chapter 4.4.1.

- *Fuel based*, based on the Trafikverkets database for the type of vehicle the fuel consumption was calculated. With the calculated amount of diesel consumed the gereeenhouse gas emissions was calculated in OCL that corresponded to an emission factor of 3.24 kg CO_2e / l.

- *Tank to wheel (TTW) and Well to wheels (WTW),* TTW is the direct emissions that occur when the fuel is consumed whereas the WTW considers the processes from extraction, production to the distribution of the fuel both dependent on the vehicle used solely based on Trafikverkets values.

Presented in Table 28 is the "Fuel based" approach based on the consumption of diesel based dependent on the distances considered for the relocation to a new site in Åre. The fuel consumption for the processes is based on two types of transportation, trucks with a trailer and personal vehicles from Trafikverket. These results were scaled up to calculate the results for Stockholm and Malmö based on their distances.

Table 28 Fuel consumption based on Trafikverket data of fuel consumption based on the Åre scenario

Process	**Distance (km)**	**Fuel consumption (l/100 km)**	**Fuel consumed (l)**
Transport of the whole building	10	37	3.7
Transport of beams	1 400	37	520
Transport of Terex TW110	20	37	7.4
Transport of L90	20	37	7.4
Transport of Maeda815	1 200	37	444
Transport of personnel	1 200	7.5	90

Considering the emissions of TTW and WTW the climate impact was calculated with respective distances covered for the different scenarios presented in Table 28, all transportation types except the transport of personnel are covered by the emissions factors of the trailer presented in Table 29.

Table 29 Emissions factors for TTW and WTW for respectively transportation type.

Transportation type	**Emission factor, WTW (kg CO_2 / km)**	**Emission factor, TTW (kg CO_2 / km)**
Personal vehicle	0.08	0.06
Trailer	0.39	0.25

Table 30 Results of Åre utilising the WTW and TTW approach

Transportation type	**Distance (km)**	**WTW and TTW (kg CO_2e)**
Transport of the whole building	10	6.4
Transport of beams	1 400	898
Transport of Terex TW110	20	12.8
Transport of L90	20	12.8

Transport of Maeda815	1 200	768
Transport of personnel	1 200	168

Presented in Figure 24 are the results of the different approaches. The two approaches utilising Trafikverkets numbers are the two results that contribute to the highest impact for all locations. Where the highest contribution corresponds to 74 kg CO_2e / m^2 BTA for the relocation to Malmö with the "Fuel based" approach. The lowest contribution in all scenarios occurs for the "Transported mass".

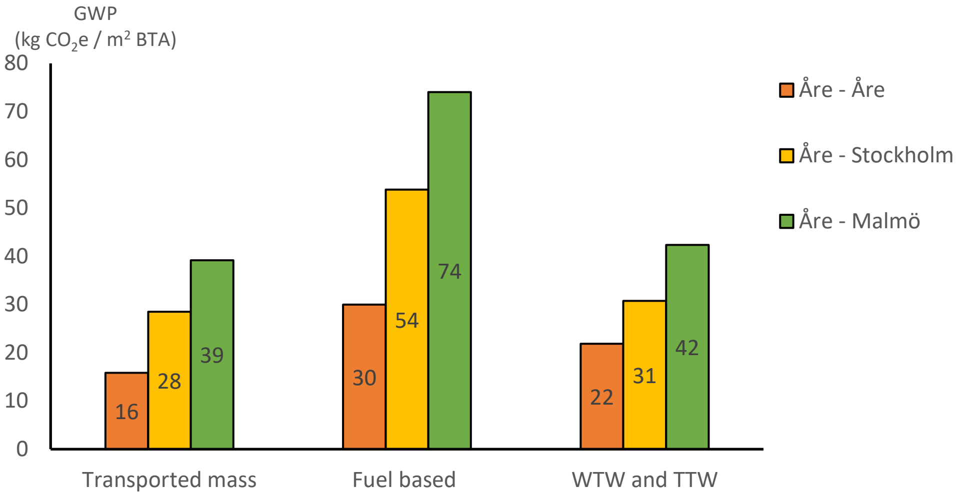

Figure 24 Impacts of different calculation methods for Case A

This analysis evaluated different calculation methods used to calculate the climate impact related to transports in Case A. Results presented in Table 31 shows that the largest total climate impact for the different calculation methods was achieved in the case with the longest transported distance, when the building was relocated to Malmö. The results showed that the *fuel-based method* resulted in the highest climate impact for the three geographical locations. The methods of *transported mass* and *TTW and WWT* showed similar results with the largest difference of 395 kg CO_2e from the relocation to Malmö.

Table 31 Total climate impact excluding B6 for Case A for different calculation method

New Site location	Distance (km)	Transported mass total (kg CO_2e)	Fuel based total (kg CO_2e)	TTW and WTW total (kg CO_2e)
Åre	10	14 447	16 230	14 614
Stockholm	650	16 040	19 233	16 327
Malmö	1 100	17 390	21 785	17 785

4.10.1 Comparison of payback time by implementing operational energy use

As the results indicate the greenhouse gas emissions vary a lot depending on the calculation utilised therefore all scenarios will be compared to evaluate the impact of the implementation of the energy use during the operational stage, B6. The simulations of module B6 include the influence of energy use over a period of 100 years for the three different geographical locations. The difference in inclination between the geographical locations is caused by the emission factors selected for each location depending on the energy use for each case, presented in Table 32 (Energiföretagen Sverige, 2022).

Table 32 Emission factors dependency of location for district heating

New Site location	Energy company	Emission factor for district heating (g CO_2 / kWh)	Emission factor Case A (kg CO_2e / year)	Emission factor Case B (kg CO_2e / year)
Åre	Jämtkraft AB	20	221	138
Stockholm	Stockholm Exergi AB	46	508	317
Malmö	E. ON Energiinfrastruktur AB	11	122	76

Figure 25 shows the simulated results for the location of the building in Stockholm for each scenario of the three different calculations methods for transportation applied in Case A. The break-even point varies between 36 – 53 years, with the shortest payback time linked to the *Fuel based method* and the longest payback time linked the *WTW and WTT method*.

The difference in the results of payback time depended on the total climate impact each case generated before the operational energy use was implemented. Since the comparison was made with the same geographical location, the three cases utilised the same emission factor for the district heating. The total climate impact for Stockholm, presented in Table 31, shows that the Fuel based method obtained the highest result of 19 233 kg CO_2e which resulted in the shortest payback time.

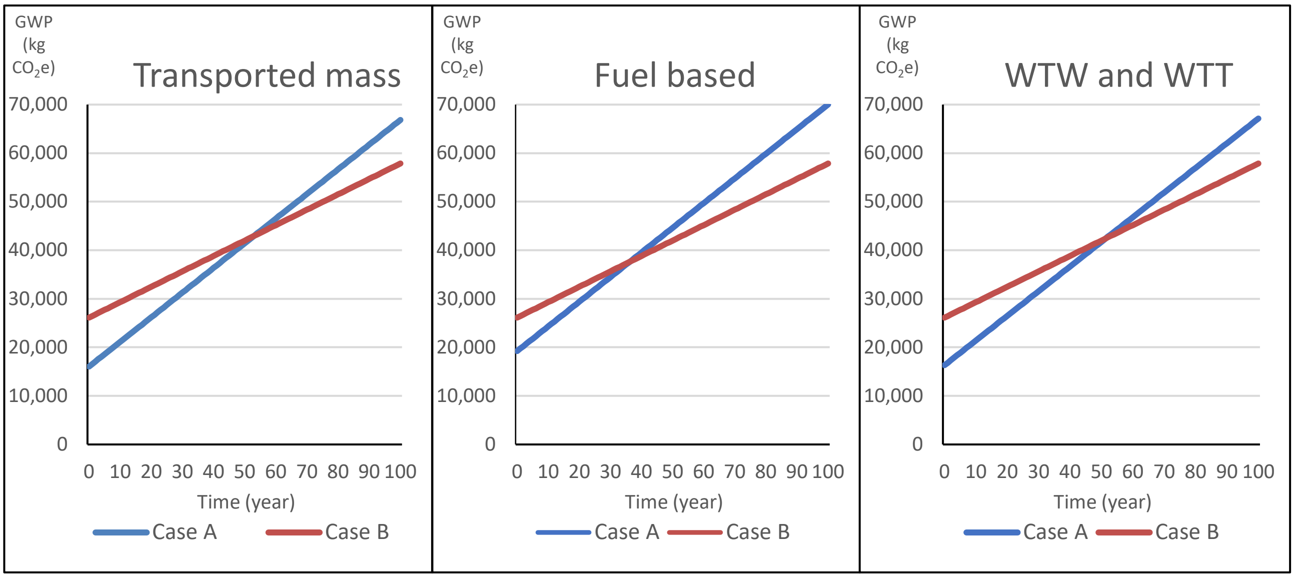

Figure 25 GWP linked to energy use (B6) over time for different Case A scenarios and Case B with the new site located in Stockholm

Figure 26 shows the simulated results for the location of the building in Malmö for each scenario of the three different calculations methods for transportation applied in Case A. The results show break-even points varying between 94 – 190 years, with the shortest payback time linked to Fuel based method.

When the building in Case A is relocated to Malmö, there is an increase in the total climate impact compared to Stockholm due to the increased transport distance. The reason for the increased payback time between Malmö and Stockholm relates to the difference in the emission factor for district heating, presented in Table 32.

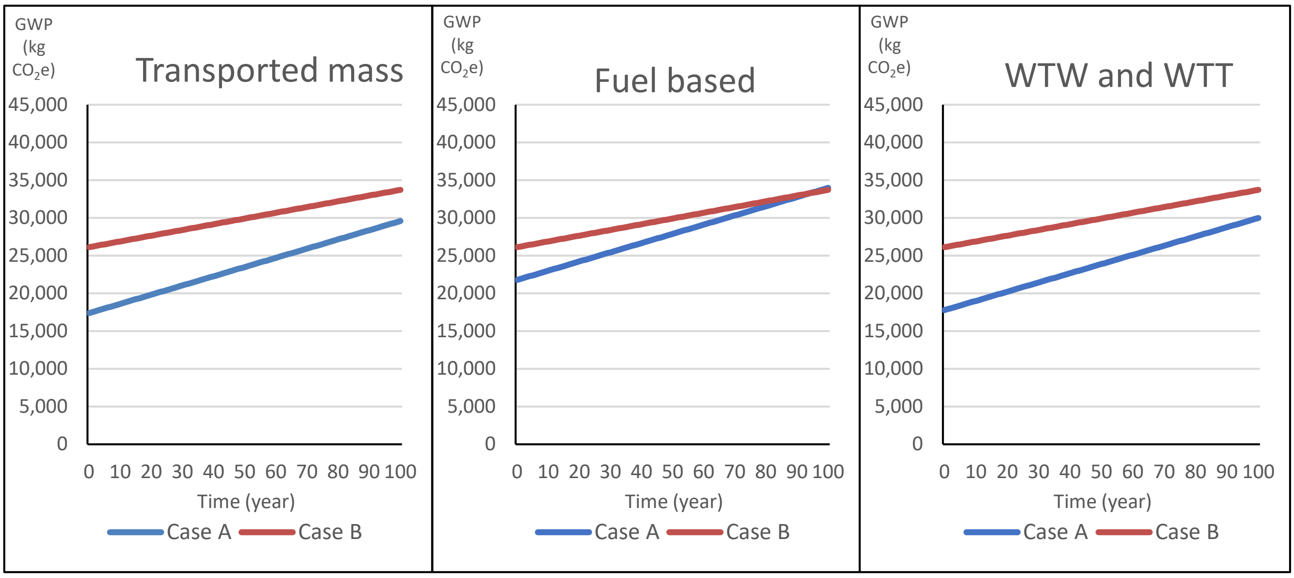

Figure 26 GWP linked to energy use (B6) over time for different Case A scenarios and Case B with the new site located in Malmö

Figure 27 shows the simulated results for the location of the building in Åre for each scenario of the three different calculations methods for transportation applied in Case A. The results show break-even points varying between 119 - 141 years, with the shortest payback time linked to Fuel based method.

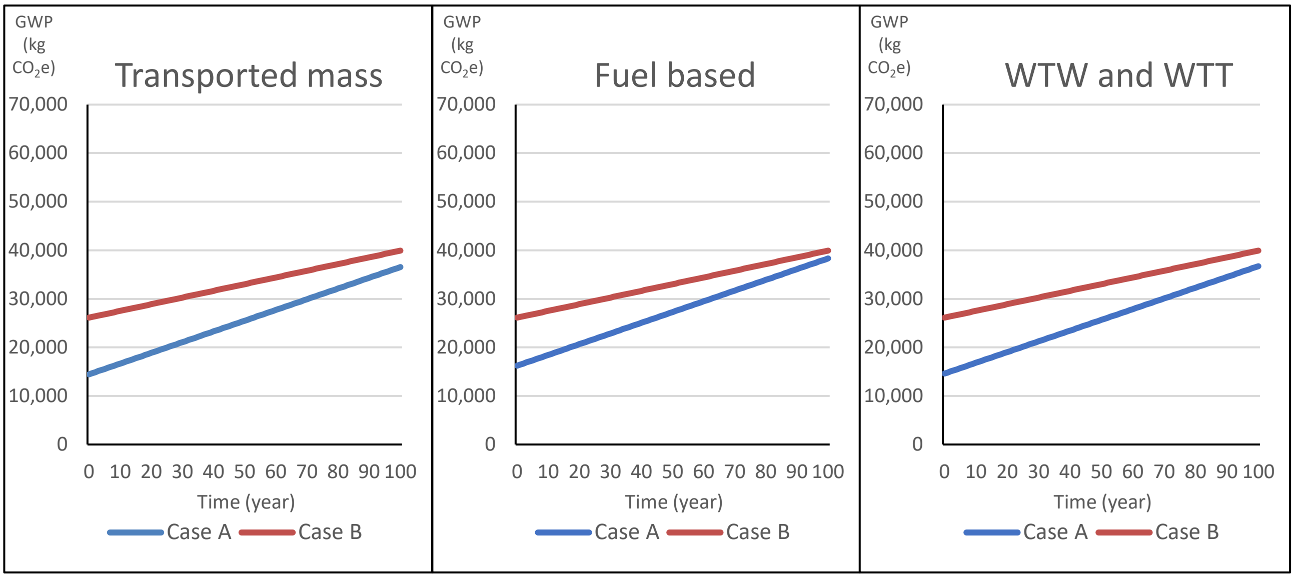

Figure 27 GWP linked to energy use (B6) over time for different Case A scenarios and Case B with the new site located in Åre

Table 33 shows a summary of the results from the analysis, indicating a variation in payback time for the different geographical locations when different calculation methods were implemented. The most significant variation occurs when the building is moved to Malmö, where the repayment period varies between 94 years to 190 years. This case measured the most significant difference in total climate impact, and the city had the lowest emission factor for district heating.

Table 33 Summary of payback-times of climate impact.

New Site location	Transported mass Payback-time (years)	Fuel-based Payback-time (years)	TTW and WTW Payback-time (years)
Åre	141	119	139
Stockholm	53	36	51
Malmö	190	94	181

4.11 Analysis Operational energy use (B6) – Sensitivity analysis

Chapter 4.8 describes the approach to calculate the impact including the stage of energy use during the operational stage for Case A and Case B. The calculations were based on statistical data for energy use in Sweden consisting of energy for space heating and domestic hot water use. To further analyze the impact of energy use, a sensitivity analysis was performed. The analysis was conducted by varying the energy use in Case A, keeping the energy use in Case B constant of the heated floor area. Values used in the analysis are presented in Table 34.

Table 34 Energy use utilized for Case A

Series	Case	Energy use (kWh/m^2 A$_{temp}$)
1	A	74
	B	119
2	A	74
	B	150
3	A	74
	B	200
4	A	74
	B	250
5	A	74
	B	300

Results presented in Table 35 show the payback time for the climate impact generated by different energy use in Case A compared to Case B which is set up with the original 74 kWh/m^2, A$_{temp}$. The presented results only compare the scenario based on LCA results utilizing the "*Transported mass*" for the A4-module in Case A. The results demonstrate an increase in energy use in Case A affects the payback time, gradually decreasing from the initial value of 119 kWh/m^2 A$_{temp}$, with the shortest payback time resulting from the highest energy use of 300 kWh/m^2 BTA. The results show that for all geographical locations, the largest difference in payback time occurs between series 1 and series 2, where energy use increases by 31 kWh/m^2, A$_{temp}$.

Table 35 Payback time for different Operational energy use in Case A

Series	Energy use (kWh/m^2 A$_{temp}$)	Payback time		
		Åre (Year)	Stockholm (Year)	Malmö (Year)
1	119	141	53	191
2	150	83	31	113
3	200	50	19	68
4	250	36	13	49
5	300	28	10	38

Values presented in Table 35 are also displayed in Figure 28. It demonstrates that the greatest decrease in payback time is found between the first two series and as the energy use is further increased, the difference decreases showing the lowest change in payback time between series 4 and series 5.

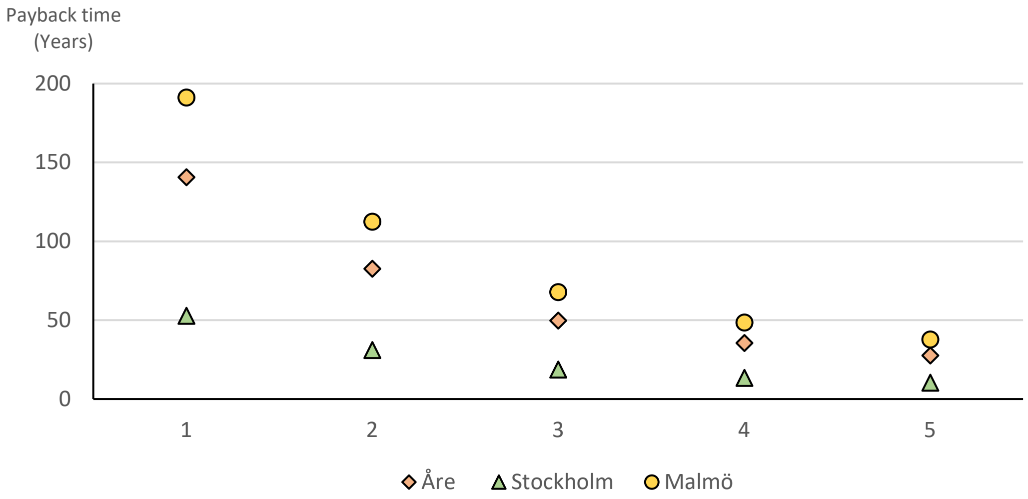

Figure 28 Payback times for different Operational energy use in Case A.

4.12 Analysis of prevented climate impact in case of reuse.

To further investigate the effects of the relocation of the building in Case A, the material flows for building materials in the entire process were assessed. Results presented in Figure 29 show that the potential saving of materials in Case A resulted in 63 tons. The distribution of saved materials is reported in Table 15, indicating that the biggest savings are related to materials in external walls, internal walls, roof, and joists. Demolished materials account for the part of the building that is demolished and managed either through recycling, incineration, or landfill. This accounts for 108 tons of materials which can be linked to the design of the relocation process where the basement is demolished. The material with the highest contribution in this result is concrete with 76 tons. New construction resulted in an added weight of 33 tons. In this category, materials added to the new site are accounted for, being the new foundation and plaster on the external facade.

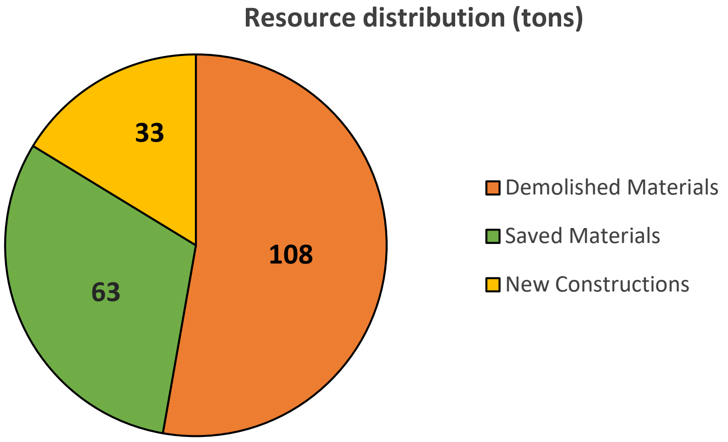

Figure 29 Material flows in different processes in Case A.

Based on this division, it was then investigated what possible savings are made when reusing materials in Case A. The savings are considered by calculating emissions from the production stage (A1 - A3) from the EPDs for each material that is moved to the new location in Case A and interpreted as prevented emissions due to reuse. Figure 30 shows the results of climate impact savings related to the reuse of the relocated materials in Case A. It is presented in positive values but can be assumed to be prevented emissions since the materials do not undergo any new production. The total climate impact saving is 19 683 kg CO_2e where the two largest contributing materials are concrete masonry units and concrete C35/45. These materials can be found in the building's load-bearing construction in the exterior walls and the joists for the main floor. The remaining materials included in the building together constitute a total saving of climate impact of 6 223 kg CO_2e.

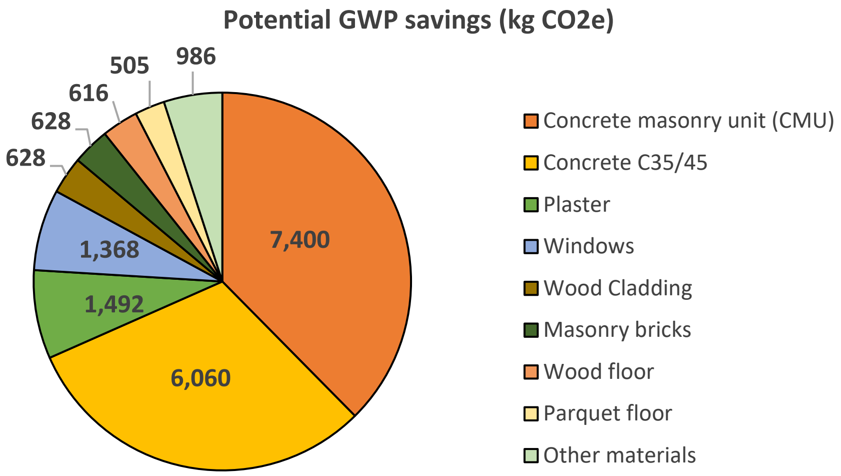

Figure 30 GWP from A1-A3 for relocated materials in Case A.

5 Discussion about assumptions and limitations in the results

In this master's thesis, a comparative study was carried out to compare two different cases of demolition and construction of a single-family house. Throughout the study, several assumptions were made and due to this following chapter discusses how the selection of these assumptions and limitations may have affected the result.

Case study building

A central part of this study was to collect sufficient data from the investigated building to be able to perform a detailed LCA. The data was collected in steps that initially involved inventorying the types of materials that were included in the building's construction. In some cases, gaps were observed in the technical description, resulting in assumptions being made based on period-typical constructions from the time the house was built. With these assumptions that were based on fact-based interpretations comes a margin of error in the design of the building. Furthermore, after mapping all the materials included in the building, quantities linked to each specific material were determined through the modelling of the house in Revit. Due to modelling being primarily performed based on drawings of the building, uncertainties are added to the resulting quantities that were compiled based on the model. For the quantities to be accurate, it is required that the modelling is performed at a high level of detail.

An additional limitation of this study connected to the inventory of the case study building did not include all the building's components. Products related to installation systems, fasteners (nails and screws), and fixed interior furnishings were not included. In addition to increased weight in a relocation, this would also mean that more material would have to be removed from the existing site and therefore included in the demolition (C1 – C4).

An important part of this study was to create a structure for the process of relocating a building from its existing site to a new site. To gather information and data regarding this process, an interview was conducted with a company specialized in lifting heavy constructions and buildings. The interview focused partly on acquiring general information regarding the work of lifting houses. Furthermore, the potential of relocating the building examined in this study was also discussed. The results from the interview, which later formed the basis of this study, were therefore based on both specific information towards the examined building as well as general information on previously performed relocations.

The specific information from the interview was the decider of the selected option of dividing the building into two parts which was due to the building having a souterrain design. Relocation of a house with a similar design had not previously been performed and therefore the method of dividing the building into two parts was selected instead. This resulted in the data used in the study being based on a previously completed project with a similar gross floor area where information regarding the process were available. The data that was applied from the previously completed project were connected to the calculation of GWP for module A5, presented in Table 18. As processes in A5 were not entirely based on the selected case study building, the extent of machinery used, and work required are therefore uncertain.

The relocation company interviewed in this study expressed their view of the procedure which was the most effective for relocating the case study building. It is important to highlight the dependency of the outcome on the results depending on the approach. With the inclusion of additional data from other relocation companies' different procedures could be addressed and further evaluated and leading to variations in the results. The outcome of the conducted relocation procedure carried out in the study indicated the best possible scenario of the reuse of the material that could be relocated, as no reconditioning of the material was addressed except the exterior plaster of the façade. Compared to other reuse scenarios for building components, they usually must be deconstructed, refurbished, and reconstructed into new buildings.

The functionality of the relocated building should also be considered, as the basement was removed based on the consultation with the relocation company enabling the relocation. The building is being relocated to a new site; it may need to be modified to meet the needs of its new occupants. The heating was assumed to be connected to the district heating network, though the installation of the heating system as mentioned was not considered in the LCA calculation. Further evaluation of the thermal comfort was not evaluated in this project nor was the fulfilment of BBR requirements.

Selection of EPD's

To perform the LCA, the next step after quantifying each material was to select an equivalent material where an EPD was available. For the existing building material and the selected EPD, they possess the same characteristic properties, but there is still uncertainty towards the management of material in the process of transportation and demolition would be treated in the actual case.

Most of the materials used in the building were from the original construction from the 1950s, meaning that it was built long before the relocation was theoretically conducted. Over time, the material in the case study building can have deteriorated which can affect how the material can later be processed. Although this potentially affects the results the selected EPDs still give a general idea of the outcome of the demolition's impact for the two cases. Considering the outcome of recycling, reuse, or energy recovery it was overviewed in the results that most of the impacts occurring in the End-of-Life stage were linked to the waste treatment in module C3. This suggests that most of the material went through a major treatment process, resulting in the disposal in module C4 being significantly reduced as less material went directly to landfill or disposal. The results indicate that the largest potential to reduce the impact of C3 correlated with potentially improving more efficient measures for dealing with the EoL-stage for each building material.

Regarding the transports necessary for the building materials for EoL-stage all were based on generic transportation distances connected to the selected EPDs which brings additional uncertainties. Since both cases are based on the same approach the comparison could considered to be validated. For all selected EPDs for the material in the EoL was declared, though for a few of them the C1 module the impact was declared as zero. Even though the impact might be low the actions required for demolition do not seem reasonable to be accounted as zero.

Reference building in Case B

In this study, the comparison was based on two different cases, where Case A aimed to calculate the climate impact of the process of relocating a building. The other case used in the comparison (Case B) measured the climate impact of a process when the case study building was demolished followed by construction of a new house. In the part of Case B that concerned the calculation for the construction of a new building, a reference building was used. The values for this reference building were based on an average from 11 one-two-dwelling houses. Information regarding each individual house design was not explored further. Although the reference building used in Case B was designed with the same floor area as the building used in Case A, it is possible that the design of the two compared buildings differ.

As the design of the reference building was not investigated in more detail, general values for energy use were implemented. Material and installation climate impacts were removed connected to the ventilation and heating system from Case B in the newly constructed building enabling the comparison of the two cases. Transparency is a key factor for the LCA as the outcome is determined by what is involved or not. The importance of stating the inputs and outputs that brings clarity to the results which can be analysed and a better understanding in general.

Selection of LCA stages

The LCA is a method to assess the potential environmental impact of a product throughout its life cycle. When the LCA-method is used to assess building, there are guidelines on how the life cycle is divided into stages representing each part of the life cycle. Each stage, described in Chapter 2.2.1, consists of multiple modules accounting for specific activities under the stage. In this study the LCA-modules included were the Product stage (A1 – A3), Construction process stage (A4 – A5), Use stage (B6), and End of life stage (C1 – C4). Furthermore, the remaining modules B1 – B5 and B7 were excluded from the calculations. Since the aim of the study was to assess the process of relocating a building, the selection of LCA modules was based on their relevance to that specific process. Inclusion of the other modules would have influenced the results but as stated this was not the primary aim of the study. Including repairs (B2), replacements (B3), and refurbishment (B4) for example would have required that the building's current condition was needed to be evaluated to make legitimate decisions on possible improvements. Furthermore, these measures would potentially affect the energy use of the building, which was not part of the study's objectives.

Two measures were eventually implemented on the new site with the new foundation and additional plaster on the external facades. As the building was relocated, the new site needed a foundation which included casting a new foundation with insulation. The additional plaster added to the exterior facades was due to the existing plaster being damaged during transportation. Although these measures would potentially influence the building’s energy use, it was not considered improvements for the energy use as it was a prerequisite for the building to function on the new site and was therefore assumed to be included in module A1 - A5. The extent of the measures was specifically selected based on the conditions of the case study building's construction and would potentially alter if another building had been examined.

Transportation (A4)

Results of the total GWP showed that in Case A where the building was relocated by 10 km, the total transport (A4.1 – A4.4) constituted a small part of the total measured climate impact in the LCA. Based on this, the result is interpreted as when a building is to be relocated, transport is not the greatest contributing factor to climate impact.

An analysis was conducted to further analyse how the impact would relate if the transport of the relocation for the case study building would vary in case of an extended distance. Two cases were calculated where the distance was increased to 600 km (Stockholm) and 1 100 km (Malmö) respectively. The result showed that the climate impact in both cases increased in relation with the increased distance. When the results from the analysis were later compared with the total climate impact that included results from the other modules, it shows that even though the transport was extended from 10 km up to 1 100 km, A4 was still not the most contributing module.

A significant change in the results of transport was discovered to be related to the type of methodology used to calculate the climate impact in module A4. In the analysis conducted in Chapter 4.10**,** the results show that depending on which method is used, the results differ. Determining what approach that is more correct than the other is difficult, therefore the investigation of the possible options was conducted and evaluated for the scenarios to the different locations. As a result of this, the different outcomes varied a lot and had a great influence on the total outcome of the climate impact for Case A and the comparison of the two cases.

Energy Use (B6)

Values for the climate impact of energy use were assessed on data based on statistics on average energy use for one- and two-dwelling houses in Sweden dependent on construction year. A limitation that may have an impact on energy use is the different outdoor climates for the new sites which can be a bit misleading for the comparison of the different geographic destinations. The only difference in impacts from the energy use stage of the LCA that was considered was the emission factors, selected based on the location of the new site. This has affected the climate payback time that was calculated between the two cases, in Chapter 4.9. Additionally, for the payback time calculated it is important to note as the electric use was neglected in the B6 module which would have further influenced the calculation of payback especially if the building was heated with electricity.

Location dependency was an important factor in evaluating the results of the different geographic sites that played a huge part in the break-even point for the different cases. As expected, the longer the distance the higher impact occurring from the A4 module. Though, with this account, the case of transportation to Malmö compared to Stockholm was still more profitable from an environmental point of view. This comes to show the importance of the emissions factor of energy which was significantly higher in the case of Stockholm compared to both Malmö and Åre. For future energy scenarios, the energy distribution most probably has transitioned towards more renewable energy sources which might result in lesser emissions occurring during the use stage for buildings and overall impact from a LCA perspective. Therefore, the perceived results comparing two different energy demands will become less significant.

For other scenarios of relocating an existing building where the building performs much better from an energy use point which usually corresponds to a higher amount of material utilized for the construction which can be correlated to a larger amount of embodied energy. The potential effects of reuse from the relocation have indicated beneficial for the environment, if the building in Åre would have had a lower energy use the number of years required before the newly constructed building performed better would probably substantially increase as this is the driving factor for the break-even point. An interesting approach would be to design buildings so they are more accessible for relocation as this would enable another dimension for decision making where before the only option was to demolish and in the best case reuse a small amount of material for other projects.

Selection of categories

The study has confined its selection of environmental impact categories to climate impact due to the reference building that Case A is being compared to, which is based on the Climate Declaration in Sweden, where only the impact on climate is considered. Although climate impact is an important environmental category, other categories could be equally influential. The incorporation of additional environmental impact categories could have increased the complexity and diversity of the results for the specific process involved especially in the relocation. While climate impact is one of the most well-researched categories obtaining a comprehensive overview but including other categories can provide a more detailed picture of various results which would be beneficial for future decision-making.

Social and economic impact

Additional determining factors for creating sustainable welfare is to consider the social and economic effects of any process. The procedure of relocating a building involves many processes which can be costly i.e., road work enabling the feasibility of the transportation building along with all other preparation work required. The social impact in addition to both the environmental and economic impacts would be interesting to assess to discover the potential consequences and benefits of either relocating or demolishing the building. Further evaluation of the social impact can be connected to the demolishment of buildings compared to preserving them. Combining and weighing all the factors to evaluate the different sustainability parameters for finalizing decision-making regarding the potential demolition of existing buildings or relocating can bring an additional dimension as the study indicate the potential environmental benefits that relocation of buildings can provide.

Potential savings from reuse

This study investigated the potential effects of reuse by comparing the climate impact of linear and partially circular material flows. The findings show that the process of relocating a building in Case A resulted in a GWP of 115 kg CO_2e / m^2 BTA, differing from the result of Case B which measured a GWP of 208 kg CO_2e

/ m^2 BTA. The most significant difference between the cases was observed in the product stage (A1 - A3), as presented in Figure 20. The preservation of material in Case A was a significant factor in Case A in the comparison having a lower total climate impact due to less material necessary to be produced.

Additionally, the study examined the amount of climate impact that could be avoided in Case A by reusing the materials in the case study building rather than producing new ones. This was assessed by calculating the climate impact that would potentially be generated in the product stage (A1 - A3) for the moved materials. The reuse of materials resulted in a prevented climate impact of 19 683 kg CO_2e. Comparing the result of the prevented climate impact to the total values for Case A and Case B, it becomes evident that material reuse has a considerable impact on reducing climate impact in Case A.

The interpretation of reuse in this analysis was based on climate impact linked to the production of the materials in modules A1 - A3. The choice not to include the other modules indicates that the results of the reuse could vary if more modules were considered. Although the analysis delimits essential steps that could change the outcome, it still demonstrates the environmental savings that can be made when materials are reused.

Circular economy during relocation

An important aspect of the model of Circular Economy relates to the idea of efficient management of materials. This alludes to how materials can be managed to extend their life span by implementing strategies such as reuse. In this study, a comparison was conducted on the potential climate impact related to the case of relocating a building compared to the building being demolished and a new one later being constructed. The main idea behind the case of relocation was to assess the possibility of implementing a strategy of reuse to a complete building. As a result of the implementation of a strategy based on reuse, in Table 16, Case A still required for new materials to be added to the building. Although the overall process in Case A can be considered an implementation of the circular model, new products were still required to be introduced to complete the relocation. The result shows, however, that the materials that are included in the move and thus saved constitute a larger proportion than the materials that needed to be added for the relocation to be possible. To lower the impact of the new materials, there are opportunities to review which materials must inevitably be supplemented and then propose how these materials can be applied from a circular perspective.

6 Conclusion

This study provides an insight in the potential environmental benefits of relocating a building compared to the case of demolishing an existing structure and constructing a new one.

To establish which stages of Case A had the greatest impact, a schematic structure was designed that included all the steps required to move the case study building. The result showed that the largest climate impact was linked to the construction and installation process in Module A5, with 44 kg CO_2e / m^2 BTA. To enable a relocation of a building, preparatory work is required before the building can be transported as well as at the new location related to the building's installation. The second largest impact could be linked to the product stage and modules A1 - A3, with 39 kg CO_2e, which was an inevitable stage as the new site partly required a new foundation and a supplementary layer of plaster on the outer facade.

To evaluate Case A's impact, a comparison was carried out with Case B, which corresponded to an alternative scenario where the case study building was demolished, and a new building was constructed based on values from a reference case. The overview result showed a difference in the distribution of climate impact between all life cycle stages, with a significant difference in the product stage. The strategy of reusing materials showed a saving potential of 89 kg CO_2e / m^2 BTA in Case A. The only modules where Case A had a larger impact than Case B was in the construction and installation stage, consisting of modules A4 and A5. In Case A, this stage was partially calculated through transports with specific distances and weights and operating hours for machines which resulted in Case A having a climate impact that was 34 kg CO_2e / m^2 BTA higher than in Case A. To enable the relocation, parts of the building were required to be demolished in Case A. When this was compared to the total demolition of the building included in Case B, the biggest difference was measured in waste processing in module C3. The main contributing factor to the difference here was related to the waste processing of the parquet flooring, which was only demolished in Case B. Completing the comparison before the energy use of the two cases the climate savings resulted in 93 kg CO_2e / m^2 BTA for the circular strategy of relocating a building, in Case A.

The implementation of operational energy use was used to calculate an environmental payback time for when Case A would measure the same total climate impact as Case B. The results indicated that the emission factor used for the district heating has a large impact on how long the payback time is. Comparing the relocation to Malmö and Stockholm for the cases, with a higher initial climate impact for Malmö due to the longer transportation it still achieved a longer pay-back time than Stockholm primarily due to the relatively higher emissions factor for district heating which is used in Stockholm compared to Malmö for district heating.

To evaluate how different parameters would influence the result and the environmental payback time, analyses of the impact of geographical location, variation of operational energy use and different calculation methods for transport were performed. It can be concluded that when you vary various parameters related to the relocation in Case A, the result changes, but that in all analyses, Case A is still environmentally beneficial compared to Case B.

7 Future work

This chapter will cover future research that could bring additional knowledge and insight to this study. The primary goal of this study was to assess the potential climate impact associated with the relocation of a case study building, by comparing it to the construction of a new building and the demolition of the existing case study building. To increase the research in this area, it would be required to undertake supplementary LCAs that examine the relocation process further. This would enable the collection of additional data, thereby enabling more comprehensive analysis and comparisons. Furthermore, there is a need to gather ongoing project data about building relocation to verify the outcomes of the current study.

The climate impact related to all HVAC installations for modules A1 - A5 was not considered in the comparison of the LCAs as not enough resources were acquired during the study for the case study building. Dependent on the HVAC installations it is also the determining factor for the type of energy source of the buildings and the deciding factor for the emission factor utilised during the B6 - module, which in this study was assumed to be district heating. For future assessment, this should be included as it could be a major contributor towards the results of the LCA regarding the environmental impact.

Considering future LCAs these should aim to incorporate additional environmental impact categories that were not included. This will lead to a more comprehensive understanding of building relocation and the comparison of constructing a new building and demolishing the case study building. By expanding the scope of analysis to include other impact categories, such as water use, acidification, and land use, among others, a more complete picture of the environmental impact can be obtained. Moreover, this would facilitate the identification of additional benefits or drawbacks of building relocation that may not have been previously considered in this study. Therefore, conducting additional LCAs with a broader scope of environmental impact categories would contribute significantly to the overall understanding of the implications of building relocation. It should be noted that certain impact categories may have a more pronounced effect on specific processes within the comparison of the study, particularly during the EoL stage. By identifying the specific impact categories that have a greater influence on certain processes, a more accurate depiction of the environmental impact of the comparison can be achieved. Therefore, a thorough examination of the interplay between impact categories and processes is necessary to fully comprehend the implications of the comparison.

The incorporation of additional modules to improve the comprehensiveness of future LCAs. Neglected modules in this study during the use-stage, such as maintenance, repair, and replacement, should be considered as they can have a significant impact on the overall environmental performance of the cases. In the context of building relocation, the potential benefits of energy efficiency measures should also be considered, specifically concerning improving the thermal resistance of the building. Such measures could reduce emissions during the energy use stage but will have a corresponding increase in the climate impact of the newly implemented materials. Therefore, there is a need to evaluate the trade-offs associated with implementing energy efficiency measures during building relocation and to integrate this assessment into LCAs.

For further studies conducting an integrated life cycle analysis that evaluates the social, economic, and environmental aspects of two cases is crucial in establishing the sustainability of a process and providing a robust basis for decision-making. In this regard, weighting and normalization techniques are essential in determining the overall sustainability of the process. For instance, when considering the relocation of a building versus the linear scenario of demolition and the potential construction of a new structure, it is important to assess the economic costs associated with the relocation process and compare them with the costs of the linear scenario. This evaluation helps in determining the most sustainable option among the two.

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Appendix A

Complete demolition corresponds to the End of Life stage, modules C1 – C4, used in Case B

Partial demolition corresponds to the End of Life stage, modules C1 – C4, used in Case A

Total demolition	🟧
Partial demolition	🟩

Category	Selected material	Quantity	Unit	Functional/ declared unit	Weight (ton)	Impact of EoL (kg CO_2 eq)	Impact of EoL (kg CO2 eq / BTA)	Impact of EoL (kg CO2 eq / BTA)
1. Foundation and substructure								
Reinforcement	Reinforcement steel (rebar), from recycled steel, 7850 kg/m3	150	kg	1 m^3	0,15	0,0011465	0,000	0,000
Concrete foundation (basement)	Ready-mix concrete, C35/45, XD1, XS1, XS2, XF2, XF3, XA2, 2250 kg/m3	19,58	m3	1 m^3	46,992	601,492	4,774	4,774
Concrete slabs	Ready-mix concrete, C35/45, XD1, XS1, XS2, XF2, XF3, XA2, 2250 kg/m3	5,79	m3	1 m^3	13,896	177,896	1,412	1,412
Concrete foundation (storage)	Ready-mix concrete, C35/45, XD1, XS1, XS2, XF2, XF3, XA2, 2250 kg/m3	1,75	m3	1 m^3	4,2	53,73	0,426	0,426
Slab edges	Ready-mix concrete, C25/30, X0, XC1, 2230 kg/m3	4,08	m3	1 m^3	9,792	123,468	0,980	0,980
2. Vertical construction and facade								
External walls and facade								
Concrete hollow stone	Concrete masonry unit (CMU), 498 mm x 88-348 mm, 3 Mpa, 650 kg/m3	6,39	m3	1 m^3	3,195	61,464	0,488	0,488

Concrete hollow stone	Concrete masonry unit (CMU), 498 mm x 88-348 mm, 3 Mpa, 650 kg/m3	21,79	m3	1 m^3	10,8935	209,584	1,663	1,663
Plaster (basement)	Dry mortar for levelling of walls and ceilings, moisture resistant, including packaging, 1-3 mm, 1.2 kg/mm/m2, 1200 kg/m3	1,92	m3	1 kg	3,072	26,72	0,212	0,212
Plaster (storage)	Dry mortar for levelling of walls and ceilings, moisture resistant, including packaging, 1-3 mm, 1.2 kg/mm/m2, 1200 kg/m3	0,291	m3	1 kg	0,4656	10,0964	0,080	0,080
Träullsplattor		3,815	m3		0,9919	39,170306	0,311	0,311
Lightweight concrete	Concrete masonry unit (CMU), 498 mm x 88-348 mm, 3 Mpa, 650 kg/m3	35,605	m3	1 m^3	23,1433	342,273	2,716	0,000
Wood cladding (storage)	Solid wood panelling and cladding, 420 kg/m3, moisture content 7%	0,136	m3	1 m^3	0,068	1,06535	0,008	0,008
Cementstryckning	-	0,544	m3	-	0	0	0,000	0,000
Asfaltstryckning	-	0,544	m3	-	0	0	0,000	0,000
Wood fibre particle board	Glass wool insulation, L=0.032 W/mK, R = 1.0 m2K/W, 32 mm, 1.36 kg/m2, 42.5 kg/m3	0,442	m3	1m^2 with a thermal resistance of 1,0 K.m^2/W with a reference service life of 60 years	0,01989	0,4075	0,003	0,000

Plaster (external)	Dry mortar for levelling of walls and ceilings, moisture resistant, including packaging, 1-3 mm, 1.2 kg/mm/m2, 1200 kg/m3	2,664	m3	1 kg	4,2624	45,337	0,360	0,000
Concrete hollow stone	Concrete masonry unit (CMU), 498 mm x 88-348 mm, 3 Mpa, 650 kg/m3	4,967	m3	1 m^3	3,22855	47,7142	0,379	0,379
Inner walls and none bearing construction								
Lightweight concrete	Concrete masonry unit (CMU), 498 mm x 88-348 mm, 3 Mpa, 650 kg/m3	6,91	m3	1 m3	4,4915	66,476	0,528	0,000
Plaster (basement)	Dry mortar for levelling of walls and ceilings, moisture resistant, including packaging, 1-3 mm, 1.2 kg/mm/m2, 1200 kg/m3	1,61	m3	1 m3	2,576	26,563	0,211	0,211
Plaster (entrance)	Dry mortar for levelling of walls and ceilings, moisture resistant, including packaging, 1-3 mm, 1.2 kg/mm/m2, 1200 kg/m3	2,107	m3	1 kg	3,3712	35,105	0,279	0,000
Interior wood cladding	Interior wood cladding with surface treatment from pine, 500 kg/m3,	1,86	m3	1m^2	0,93	176,9191655	1,404	1,404
Clinker	Ceramic floor tiles, 8.6 mm, 17.7 kg/m2, 2058 kg/m3	0,124	m3	1m^2	0,2852	0,22224436	0,002	0,000

3. Horizontal construction: beams, floor and roof etc								
Concrete floor (entrance plan)	Ready-mix concrete, C35/45, XD1, XS1, XS2, XF2, XF3, XA2, 2250 kg/m3	16,4	m3	1 m3	12,025	504,16	4,001	0,000
Linoleum flooring	Linoleum flooring, 2.25 mm, 2.9 kg/m2	0,18	m3	1m²	0,2484	20,08	0,159	0,159
Clinker	Ceramic floor tiles, 8.6 mm, 17.7 kg/m2, 2058 kg/m3	0,04	m3	1m²	0,092	4,034511	0,032	0,000
Natural stone floor	Porcelain stoneware floor tiles, 21.83 kg/m2	5,3	m2	1m²	0,276	6,307	0,050	0,000
Wood trusses	Prefabricated wooden roof truss element with nail plates, 57.57 kg/unit, 470 kg/m3, moisture content: 17%	2,15	m3	Unit	1,075	627,897731	4,983	0,000
Wooden floor (attic)	Interior wood cladding with surface treatment from pine, 500 kg/m3, 14x120 mm, 8.92 m of wood cladding/m2	2,3	m3	1m²	1,15	213,25824	1,693	0,000
Tongued and grooved board (Roof)	External wood cladding with surface treatment from spruce, 465 kg/m3, 19x145 mm, 7.69 m of wood cladding/m2	3,652	m3	1m²	1,826	218,3208	1,733	0,000
Tongued and grooved board (Storage room)	External wood cladding with surface treatment from spruce, 465 kg/m3, 19x145 mm, 7.69 m of	0,38	m3	1m²	0,19	22,942641	0,182	0,182

	wood cladding/m2							
Steel tiles roof	Steel cladding tiles for roofs, 14.32 kg/m2	0,238	m3	1m²	1,8683	0,0029489	0,000	0,000
Steel tiles storage roof	Steel cladding tiles for roofs, 14.32 kg/m2	0,024	m3	1m²	0,1884	0,00288493	0,000	0,000
Gypsum	Gypsum plasterboard, regular, 12.5 mm, 8.6 kg/m2	1,3	m3	1m²	1,248	62,0396	0,492	0,000
Bitumen membrane (roof	Bitumen membrane for roof waterproofing, 5.36 kg/m2	0,159		1m²	0,1431	0,26679	0,002	0,000
Bitumen membrane (storage roof)	Bitumen membrane for roof waterproofing, 5.36 kg/m2	0,017	m3	1m²	0,0153	0,028482	0,000	0,000
Cellulose loose-fill insulation (attic)	Cellulose loose-fill insulation, L = 0.038 W/mK, 26-60 kg/m3	9,96	m3	1 kg	0,2988	9,11	0,072	0,000
Cellulose loose-fill insulation between the spruce	Cellulose loose-fill insulation, L = 0.038 W/mK, 26-60 kg/m3	9,27	m3	1 kg	2,781	8,49	0,067	0,000
Wood spruces 2''x4''	Planed and strength-graded timber, pine or spruce, 460 kg/m3	0,61	m3	1 m3	0,305	456,35611	3,622	0,000
Hardwood parquet flooring	Hardwood parquet flooring (oak), 22 mm x 129mm, B-2.0, 15.5 kg/m2, 725 kg/m3	2,12	m3	1m²	1,378	2786,29	22,113	0,000
Reinforcement steel (beams)	Reinforcement steel (rebar), from recycled steel, 7850 kg/m3	400	kg	1 kg	0,4	0,003052	0,000	0,000
4. Other structures								

Concrete stairs	Precast concrete stairs	0,59	m3	1 ton	1,416	20,14	0,160	0,1598
Brick Chimney	Clay bricks, brown, produced with natural gas, 1450-2000 kg/m3	1165	m3	1 ton	1,631	6,629	0,053	0,0526
Brick Chimney	Clay bricks, brown, produced with natural gas, 1450-2000 kg/m3	2,14	m3	1 ton	2,996	12,193	0,097	0,0000
Porch	External wood cladding with surface treatment from spruce, 464 kg/m3, 19x145 mm, 7.69 m of wood cladding/m2	2,5103		1m²	1,25515	299,61812	2,378	2,3779
5. Windows and doors								
Exterior wooden door	Exterior wooden door, unglazed, biogenic CO2 not subtracted (for CML), 39.3 kg/m2	2,13	m2	Door set	0,084	1,2256	0,010	0,0097
Wooden entrance door	Wooden entrance door with glass openings, 40.28 kg/m2	2,13	m2	Door set	0,086	1,2566	0,010	0,0100
Fixed window	Fixed window with wooden frame and aluminium cladding, triple glazed, per unit, U-value = 1.0 W/m2K, 1.23 m x 1.48 m, 62.36 kg/unit	21	pieces	1m²	1,3	51,055	0,405	0,2127
Interior door	Wooden interior door, per m2, 1.23m x 2.18m, 22.6 kg/m2	15,4	m2	Door set	0,35	5,1045674	0,041	0,0405

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