Life Cycle Assessment of buildings and courtyards

A case study in Helsingborg

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Master thesis in Energy-efficient and Environmental Buildings

Faculty of Engineering | Lund University

Lund University

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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

This thesis investigates the climate impact of a newly constructed residential complex in Oceanhamnen, Helsingborg, through an extended life cycle assessment (LCA) covering both building and non-building elements such as road infrastructure, inner courtyards, external installations, that area often overlooked in conventional assessments. The aim is to develop a replicable method to quantify the global warming potential (GWP) of the entire complex. The study also compares the climate impact of the building and its surroundings to identify key areas for emission reduction and proposes design improvements to support the transition toward climate neutrality.

Separate methodological frameworks were introduced for assessing the GWP of building components and non-building site elements. For the building, a dynamic energy simulation using Rhinoceros and Grasshopper was combined with a detailed material-based LCA using Brimstone, incorporating stages A to C. For non-building elements a custom workflow in Excel was applied, integrating Environmental Product Declarations (EPDs), transport scenarios and earthworks emissions. This dual-path approach made it possible to compare and combine the building and non-building elements within one carbon assessment framework. A design improvement scenario was introduced focusing on buildings structural system. Timber-based materials with carbon-storing properties replaced the most part of the above ground reinforced concrete structure systems.

Results show that non-building elements account for approximately 4% of total emissions, significantly lower than the building itself, which accounted for the remaining 96%. The redesign achieved a 30% reduction in total GWP. Structural systems were identified as the most impactful building elements and the ones that the focus should be put when aiming for carbon footprint reduction.

Preface

This study is the conclusion of our two-year studies in the master program in Energy-efficient and Environmental Building Design at Lund University, based at campus Helsingborg in Sweden.

Acknowledgements

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We extend our sincere appreciation to the Helsingborg Government, whose provision of essential information enabled us to access the necessary data for this study.

Our heartfelt thanks go to Johan Holmqvist and Sara Johansson from IVL, whose generous support helped us resolve technical challenges in calculating the LCA of both building and non-building elements.

Finally, we would like to express our gratitude to Martin Forsberg from the Helsingborg Government for providing the detailed installation drawings of the building surroundings.

Contributions

This thesis was completed as a collaborative effort, with each member responsible for distinct parts of the study:

- Xiaoqi was responsible for the building-related aspects of the study. Her contributions included conducting the energy simulation, performing the life cycle assessment (LCA) of the building and proposing improvements to the building design.
- Natalia focused on the non-building elements of the project. She carried out the LCA of infrastructure, greenery, installations, discussed transportation scenarios and environmental impact of earthworks.

Both members contributed to the integration of their respective findings into the thesis and participated in the final editing and review process.

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Abbreviations

GHG:	Green House Gass
GWP:	Global Warming Potential
LCA:	Life Cycle Assessment
EPD:	Environmental Product Declarations
EPC:	Energy Performance Certificate
GH:	Grasshopper
HB:	Honeybee
LB:	Ladybug
CS:	ClimateStudio
WWR:	Window-to-Wall Ratio
BTA:	Building Total Area
$A_{temp:}$	Heated floor area
U-value:	Thermal transmittance
COP:	Coefficient of Performance
PV:	Photovoltaic
DHW:	Domestic Hot Water
SAP	Standard Assessment Procedure
BM	Byggsektorns Miljöberäkningsverktyg
FU	Functional Unit
CLT	Cross-Laminated Timber
GLT	Glue-Laminated Timber
LVL	Laminated Veneer Lumber

1. Introduction

1.1 Background

Global warming is accelerating, primarily due to increased human activities, mainly greenhouse gas (GHG) emissions. To limit global warming to 1.5°C, the Paris Agreement was introduced as a milestone in the multilateral climate change process, mandating that GHG emissions peak before 2025 and decrease by 43% by 2030(*The Paris Agreement | UNFCCC*, n.d.). Building upon this, the Green Deal of the European Union (EU) operationalizes climate action through some targets, such as reducing 55% GHG emissions by 2030 (relative to 1990 levels) and achieving climate neutrality by 2050 (*The European Green Deal - European Commission*, 2021).

Consistency with the Paris Agreement, Sweden's climate policy framework, introduced by The Swedish Parliament in 2017, sets a goal of achieving zero net GHG emissions in to the atmosphere by 2045 (Regeringskansliet, 2021). Moreover, the Helsingborg government was selected as one of 100 EU cities committed to becoming climate-neutral by 2030, service as pioneer to accelerate transition in other areas in the spring of 2022 (*Climate Neutral 2030*, n.d.),(*Climate City Contract 2030 | Viable Cities*, n.d.).

Achieving this ambitious target requires action across multiple sectors, particularly those with high GHG emissions. Among the major industries, the construction sector plays a critical role as the largest contributors to environmental impact with the highest GHG emissions (37%). Additionally, it accounts for 40% of global materials consumption, 40% of primary energy, and 40% of annually waste generation (*A Review of the IPCC Assessment Report Four, Part 1: The IPCC Process and Greenhouse Gas Emission Trends from Buildings Worldwide - GJ Levermore, 2008*, n.d.),(*CO2 Emissions from Buildings and Construction Hit New High, Leaving Sector off Track to Decarbonize by 2050*, 2022). In 2009 alone, the sector emitted 5.7 billion tons of GHGs which led to 23% of the emissions of global economic activity. This figure is predicted to exceed six billion by 2045(*[PDF] A Review of Carbon Footprint Reduction in Construction Industry, from Design to Operation | Semantic Scholar*, n.d.).

This presents an important contradiction: despite the construction section is the major contributor to GHG emissions, the housing demand continues to rise. Despite growing environmental concerns, the need for new residential construction remains urgent, particularly in regions facing housing shortages. For instance, the Swedish National Board of Housing has conducted new calculations of the long-term national and regional housing demand, estimating that 523,000 new dwellings will be required between 2024 and 2033 to achieve a balanced housing market (*523 000 nya bostäder behövs de närmaste tio åren*, 2024).

GHG emissions are unavoidable throughout the entire lifecycle of both new and existing buildings. In 2022, buildings' direct CO_2 emissions decreased to 3 Gt, while the indirect emissions increased to nearly 6.8 Gt. Notably, 2.5 Gt of these indirect emissions were associated with building construction, including the manufacturing and processing of cement, steel, and aluminum from building (*Buildings*

- *Energy System*, n.d.). Therefore, it is essential that all actors across the building values chain adopt mitigation and adaptation strategies to reduce the sector's climate impact.

With the increasing emphasis on climate neutrality, an increasing number of energy-efficient buildings are being constructed with significantly reduced operational energy demand. However, the embodied carbon of these buildings with technical systems and energy-efficient materials has become a more important contributor to total life cycle carbon emissions (Alam & Devjani, 2021). In addition, operational energy consumption of those buildings should not be underestimate. Despite energy-efficient designs, several buildings have been found to consume more energy than original predicted. This discrepancy is often attributed to insufficient training or inexperienced among facility managers may which can lead to the potential misuse or overuse of energy (Alam & Devjani, 2021).

Therefore, both embodied and operational emissions mut be addressed to achieve truly climate-neutral buildings. To achieve this goal, several improvements can be implemented, such as the use of alternative materials, additives, techniques or systems which have the potential to reduce CO_2 emissions by up 90% at various stages of construction and building operations.(*[PDF] A Review of Carbon Footprint Reduction in Construction Industry, from Design to Operation | Semantic Scholar*, n.d.)

However, those construction sector typically accounts only for the energy used in construction, heating, cooling and lighting of buildings, along with energy consumption of installed appliances and equipment (*Buildings - Energy System*, n.d.). Limited research has considered the detailed data impact of surroundings elements such as infrastructure, installations, courtyards, greenery and street furniture, which also contribute to overall GHG emissions. For example, studies have shown the surrounding infrastructure such as pavement can also generate substantial GHG emissions, with raw material production being the dominant contributor (*[PDF] A Review of Carbon Footprint Reduction in Construction Industry, from Design to Operation | Semantic Scholar*, n.d.),(Sizirici et al., 2021). This indicates the necessity to these non-building elements when assessing the environmental impact of construction.

Consequently, this thesis expands the scope by incorporating both the construction sector and its surroundings to provide a more comprehensive analysis

1.2 Objectives

This study focuses on Helsingborg's newly developed Oceanhamnen area - Etapp 2, see Figure 1.1, including the buildings, courtyards, surrounding road infrastructure and external installations systems. This case study was selected because it is a part of a newly developed low-carbon city district, offering an opportunity to explore sustainable urban planning and design in a real-world context. In the Etapp 2, unlike Etapp 1, the building in this phase was already required to include a climate report. This provides a valuable foundation for benchmarking and assessing environmental performance.

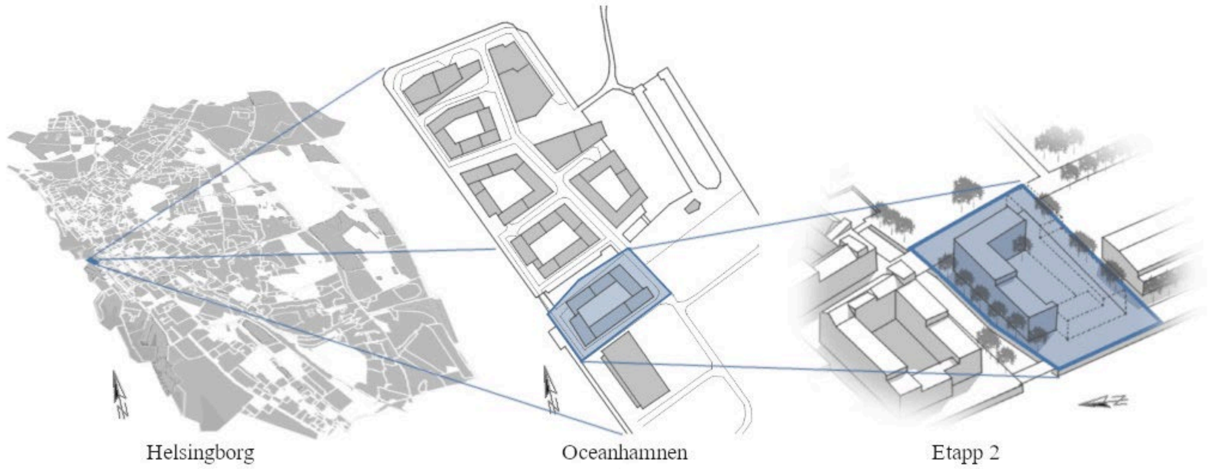

Figure 1.1: Studied area of Etapp 2 in perspective to Oceanhamnen and Helsingborg

The goal of this study is to provide a more comprehensive global warming potential (GWP) of the studied building and to address the current research gap regarding the GHG emissions associated with its surroundings later called in this study – non-building elements. This term refers to the physical features located within the immidiate building plot but outside the main building structure. They contribute to the functionality, accessibility and aesthetic quality of the site's external environment. Better understanding of distribution of GWP within building complexes allows for identifying the most impactful components to focus on during design process. There are three main objectives guiding this work.

1. To quantify the climate impact, more specifically the GWP of both the building and its immediate surroundings, introducing an extended life cycle assessment. Figure 1.2 depicts an overall scope of the study with elements that were included and excluded from performed LCA. It was aimed to develop a replicable method calculating LCA of a whole building complex.

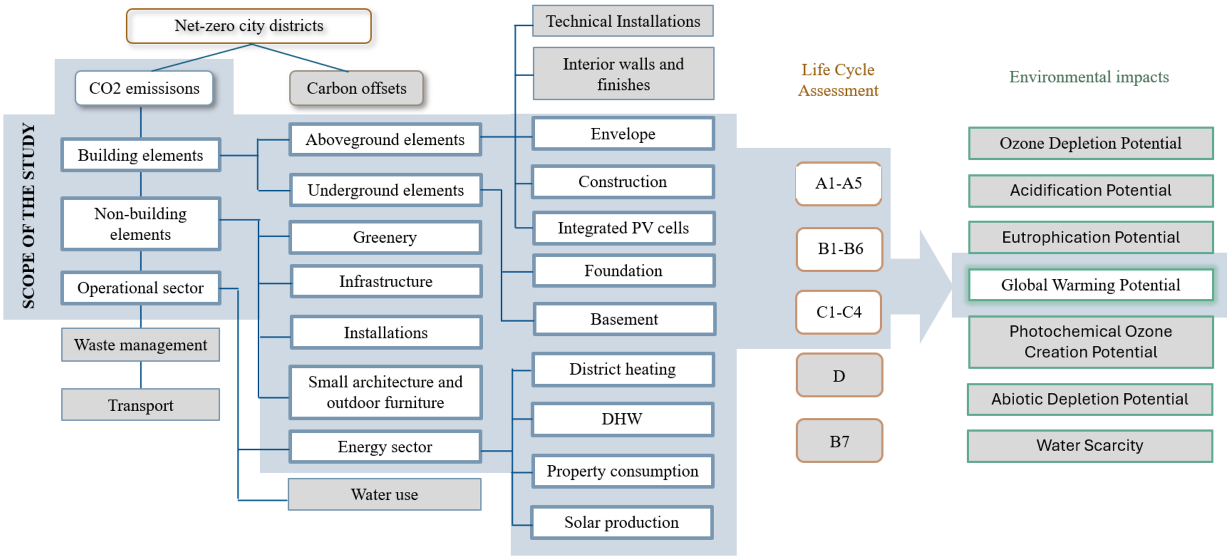

Figure 1.2: Visual representation of the scope of the study- included and excluded elements

2. To compare climate impacts of the building to its surrounding structures is another important point of this thesis. The goal is to examine the significance of each element and provide an overview, where in the building complex the highest environmental impact lies.

3. To introduce possible improvements to studied context. Alternative design of the building may indicate the course of action that supports the transition toward climate neutrality.

1.3 Research questions

The research questions listed below are expected to be answered in this work. They give a clear direction on the most important focuses of the study.

- What significance do non-building elements have in comparison to the building itself in a matter of GWP?
- Which elements of the building's surrounding have the most impact on carbon footprint?
- What design choices support carbon footprint reduction?

1.4 Limitation

This study included several limitations and aspects that were disregarded. Specifically, it focused solely on a new constructed residential building and its adjunction surroundings located in the Etapp 2 of Oceanhamnen, overlooking the second building which construction has not started yet.

Life cycle assessment (LCA) was used to evaluate the environmental impact of the studied building, focusing primarily on embodied carbon and the carbon emissions of operative energy use under the GWP indicator, while excluding the D stage. However, a more exhaustive LCA could also incorporate additional environmental categories such as ozone layer depletion potential, acidification potential, and eutrophication potential, which were not considered in this research.

Compared with the climate report provided by Bygg Bostad Syd, 9% of the total GWP in the original scenario of building remains unaccounted for. In addition, several interior materials were absent from the climate report and the corresponding database could not be found. As a result, these materials were not included in the subsequent calculations. Furthermore, due to the lack of detailed construction and technical drawings, many details were assumed when reconstructing building original structure system and its surrounding elements.

In the calculation of LCA for non-building elements, a number of simplifications have been applied due to the lack of established data sources and standardised assessment frameworks.

In designing the alternative structure system of building, although the empirical values can be obtained from related literature studies, accurate calculations were not performed due to limited experience in structural engineering. In addition, the evaluated alternative strategies were limited to a chosen range, meaning that there were most likely other variables that proved to be more optimal than those regarded in this study, such as carbon-storing materials that can be used to replace some of the envelope materials.

2.Methodology

2.1 Overview

The methodology identifies building and non-building elements within the urban fabric. While LCA of buildings is a well-established practice with widely available data and standardized methods, the environmental impact of non-building elements – such as earthworks, infrastructure and open spaces – remains less commonly assessed. To fill this methodological gap, the study adopts two parallel workflows. The most effective calculation paths were chosen for each building and non-building elements.

When introducing an improved design, to be able to accurately assess its potential in lowering carbon footprint, it is important to realise that modifications of used materials not only change embodied carbon but also impact building's operational performance. Operational stages, particularly energy use (B6), are playing a significant role in LCA of buildings. To commit to that, the case building was modelled using Rhinoceros 3D (Associates, n.d.) and its energy consumption of it was simulated using Grasshopper (GH) (*Grasshopper*, n.d.). The integrated approach ensures precise control over performance parameters and balance between embodied and operational impacts.

2.2 Workflow and Methodological Phases of the LCA

An overview of the methodology is presented in the diagram below, see Figure 2.1, and is followed by a detailed explanation of each phase.

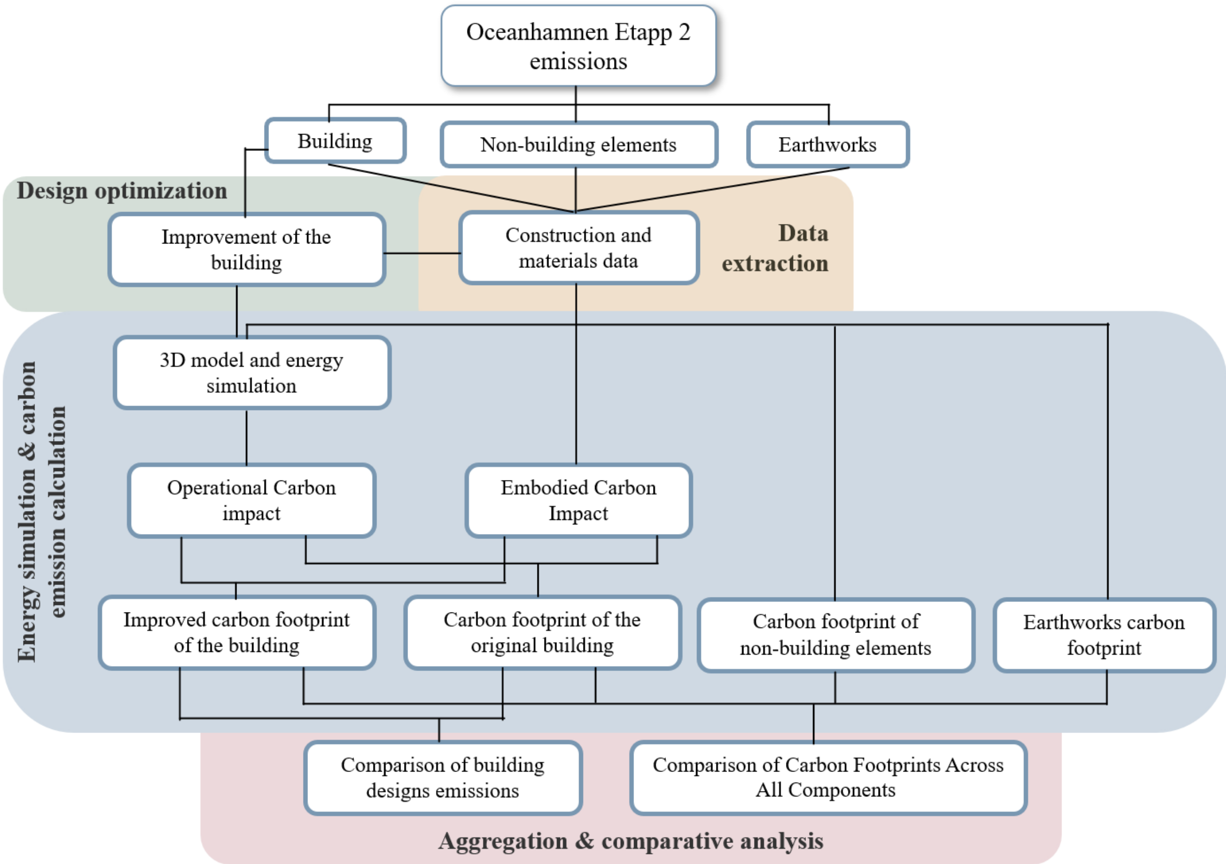

Figure 2.1: Diagrammatic workflow of the study

Data extraction

The construction details and material specifications of the building were collected from architectural documentation and construction drawings provided by PEAB and Åkermans Ingenjörsbyrå for the case study. Material layers and technical installations were extracted from the architectural and installation drawings, providing information on surrounding design and its specifications. These elements were then translated into measurable parameters - such as thicknesses, volumes and masses – allowing for true to life inputs into the life cycle assessment calculations.

Simulation & carbon emission calculation

Based on collected data, a complete 3D model of the building was developed, accurately reflecting its physical and material characteristics. This model serves as the foundation for embodied carbon calculations and energy simulations.

Using Grasshopper (GH) plugins: Honeybee (HB) (*Ladybug Tools | Honeybee*, n.d.), Ladybug (LB) (*Ladybug Tools | Ladybug*, n.d.) and ClimateStudio (CS) (*ClimateStudio for Grasshopper*, n.d.) for energy simulation and Energyplus (*EnergyPlus*, n.d.) for calculation engine, the building's yearly energy demand was calculated through dynamic simulation. In order to ensure the accuracy of the simulation results, the simulated energy consumption of the base case was compared to the energy calculation provided by PEAB. The results were then compared to the values stated in the building's Energy Performance Certificate. This annual energy uses of the building were translated into kilograms of CO_2 equivalent over a 50-year reference period, allowing for integration into the operational carbon component of the LCA.

The Brimstone Grasshopper plugin and newly developed components were used to calculate the embodied carbon of materials of building's construction. It enabled fluent recalculations during the design improvement process, allowing for an assessment of how material substitutions influence overall embodied carbon footprint. Due to the limitation of Brimstone, only the carbon emission of A stage and B6 can be calculated by using Boverket's Klimatedatabas (*Boverkets Klimatdatabas - En Tjänst Från Boverket*, n.d.). Therefore, several new components were customized for extending system boundary from A stage to C stage and database which includes Boverkets Klimatedatabas, Byggsektorns Miljöberäkningsverktyg (BM) database and individual EPDs.

The embodied carbon footprint of non-building materials was calculated using Environmental Product Declarations (EPDs) specific to each material or, when unavailable, for materials with similar functions. The process was conducted using Microsoft Excel, which provided flexibility for making necessary adjustments and testing out different types of calculations as the analysis progressed. In order to examine contextual relevance of EPD A4 and C2 stages, transport related emissions were also estimated based on scenarios tailored to the Oceanhamnen location.

Soil excavation was recognized as a possible distinct source of carbon emissions, strongly linked to the construction stage of the non-building elements as well as building itself. Given its environmental impact on both, earthworks were calculated as a separate category within the analysis.

Design optimization

Improved design choices aimed at reducing environmental impact were implemented directly into the building model, resulting in a modified version with the potential for a lower carbon footprint. This updated model reflects alternative materials, construction strategies or design adjustments and is the basis for comparative analysis to the original scenario within the LCA framework. The energy simulation and carbon footprint calculation were conducted on the same terms as for the original scenario.

Aggregation & comparative analysis

As a result of the calculations - combining the operational energy use (B6) with the embodied carbon footprint - the total carbon footprint was determined for both the base case building and the improved design. The two scenarios were then compared to analyse emissions reduction potential.

The results of embodied carbon of the non-building materials along with the emissions associated with the earthworks were expressed in multiple functional units to enable various types of comparisons across different scales and scenarios.

With the carbon footprints of both the building and non-building elements calculated, we were able to compare the significance of the non-building components within the specific building complex, as well as assess their broader relevance on a more universal scale.

2.3 Assessment Scope and Included Components

Table 2.1 below illustrates the extended scope of the life cycle assessment (LCA) carried out in this study, highlighting the additional elements—such as groundwork and integrated solar panels—that go beyond traditional assessment boundaries. System boundaries are based on the SBEF building elements table with additions (*7 Resurssammanställning v1.1 2020-12-07.Pdf*, n.d.).

Table. 2.1. Elements of LCA calculation divided into required by Climate Declaration (dark blue cells), in The Climate Report (light blue cells) and extended by this study (green cells).

0 Demolition and Removal	00 Combined	01 Dismantling	02 Decontamination and light demolition	03 Heavy demolition	04 After-treatment	05 –	06 Core drilling	07 Work for installations	08 –	09 –
1 Groundwork	10 Combined	11 Clearing, demolition, relocation	12 Excavation, backfilling	13 Ground reinforcement drainage	14 -	15 Pipes, culverts, tunnels	16 Roads, surfaces	17 Fences	18 Paving, retaining walls, complementary structures	19 Other groundworks
2 Building Structure	20 Combined	21 -	22 Excavation, backfilling	23 Ground reinforcement drainage	24 Foundation structures	25 Culverts, tunnels	26 Garages	27 Ground slab	28 Building extension/ complement	29 Other building structure
3 Load-bearing Structure	30 Combined	31 Structural walls	32 Structural columns	33 Prefab Elements	34 Structural joists, beams	35 Steelwork	36 Structure, stairs, elevator shaft	37 Composite roof structure	38 Complementary structures	39 Other structure
4 Roof	40 Combined	41 Roof structure	42 Roof completion	43 Roof covering	44 Roof eaves and gables	45 Roof openings and complements	46 Sheet metal	47 Terrace roofs, balconies	48 Roof structure complements	49 Other roof components
5 Facades	50 Combined	51 Wall completion	52 -	53 Facade cladding	54 -	55 Windows, doors, entrances	56 -	57 -	58 Interior walls of facade structure	59 -
6 Room Structure Completion	60 Combined	61 Inside outer wall	62 Subfloor	63 Interior walls	64 Interior ceiling	65 Interior doors, glazed partitions	66 Interior stairs	67 -	68 Room structuring complements	69 Other room structuring
7 Interior Surface Room Components	70 Combined	71 -	72 Interior floors, stairs	73 Interior wall	74 Interior roof, ceiling	75 Painting	76 White goods	77 Cabinet joinery	78 Room components	79 Other room components
8 Installations	80 Combined	81 Integrated solar cells	82 Process	83 Large kitchens	84 Sanitation, heating	85 Cooling, air	86 Electricity	87 Transport	88 Control and regulation	89 Other installations
9 Common Works	90 Combined common works	91 Common works	92 -	93 -	94 -	95 -	96 -	97 -	98 -	99 -
Additions (Extended SBEF items)		101 A5.1: Waste, packaging, and waste management	102 A5.2: Construction site vehicles, machines and equipment (energy incl. fuel, etc.) <5S	103 A5.3: Temporary cabins, offices, storage (energy incl. heating, etc.)	104 A5.4: Other energy use during construction (e.g. gas/oil/ fuel, district heating, purchased electricity, etc.)	105 A5.5: Other environmental impacts from the construction process				

Based on guidelines of the Climate Declaration (2022)(*Limit Values for Climate Impact from Buildings and an Expanded Climate Declaration*, n.d.), the elements that are claimed to be included in the LCA are those that form the load-bearing structure, envelope and interior structure of the building. That is understood as all components contained within the building's main frame exterior roof and facade systems, which define the thermal and physical boundaries of the building. Additionally, selected parts of the substructure, such as foundation structures and the slab on ground are also included.

The Climate Report provided by Bygg Bostad Syd filled up the room structure completion category. It proposes the inclusion of interior surface layers, such as ceiling finishes, which are often excluded in more traditional assessments.

The Housing Authority Proposal for the year 2027 (*Limit Values for Climate Impact from Buildings and an Expanded Climate Declaration*, n.d.) recommends to extend these boundaries for the construction phase, including all internal partitioning elements, fixed furnishing and technical installations. Furthermore, it proposes the inclusion of interior surface layers, such as ceiling finishes.

The extension of the LCA proposed in this study goes beyond both the current Climate Declaration (2022) and the Climate Report. To consider even broader scale of environmental impact, it was decided to include Groundwork elements such as roads and green spaces but also smaller ones as pipelines and street furniture. Solar panels were also incorporated. Including those elements, the study aims to assess more exhaustive carbon footprint, especially in the context of complex urban development's striving for carbon neutrality.

The stages considered in this calculation are highlighted in blue in the Figure 2.2. They are aligned with the EN: 15978 standard (*PN326-BRE-EN-15978-Methodology.Pdf*, n.d.).

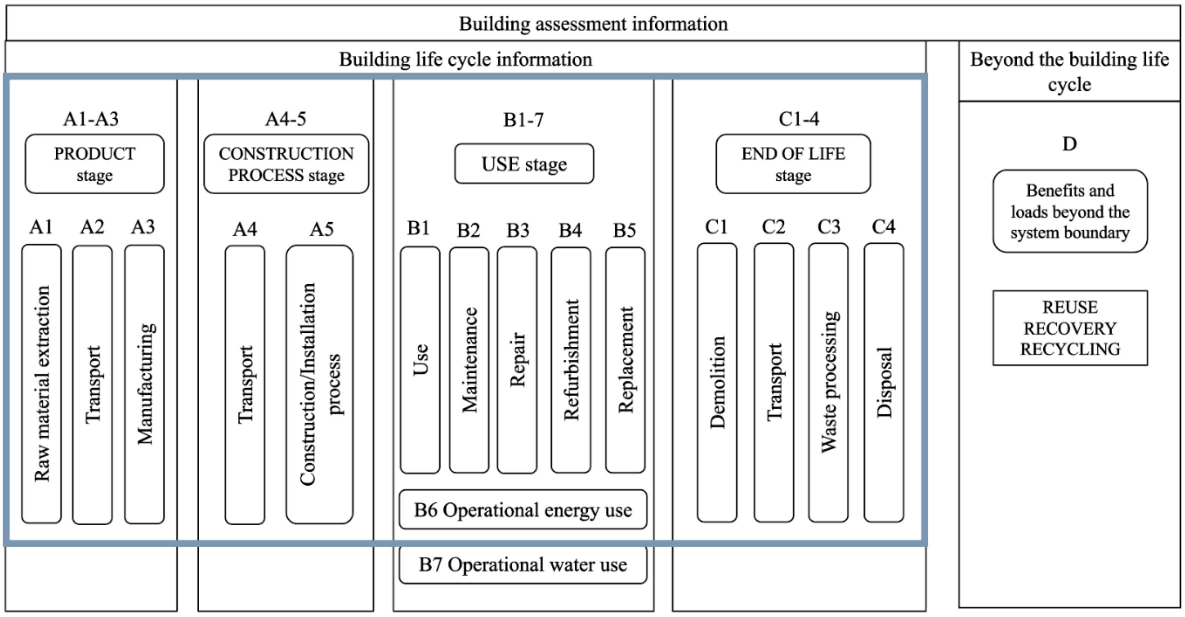

Figure 2.2: Life cycle assessment stages according to standard EN:15978

The life cycle assessment (LCA) calculations in this study focus on the A to C stages—from production and construction to use and end-of-life - while excluding the D stage (the potential for reuse or recycling) due to resource limitations and the frequent lack of opportunities to reuse building and non-building elements. The absence of well-established systems for reusing or recycling materials often complicates the accurate assessment of the D stage. That is why this study prioritizes the stages that can be better calculated with more reliable data. The assessment conducted is then giving a clearer understanding of environmental impact stages associated with material production, construction and demolition omitting possible potential for materials recovery or reuse.

For the building-related components, both the production and end-of-life phases (stage A and C) are fully considered. The use phase (stage B), which includes product maintenance, repair, refurbishment, replacement and operational energy use over a 50-year life span (modules B2-B5 and B6), is also included in the assessment.

For non-building elements, the assessment generally follows the same system boundaries as those for building components. However, operational aspects of Stage B, specifically B6 (operational energy use) such as outdoor lighting, irrigation pumps etc. and B7 (operational water use), are excluded from the calculations. This exclusion is due to the fact that the non-building elements included in the assessment do not directly contribute to operational energy consumption or maintenance activities. As a result, these stages were not applicable to the non-building components, and their environmental impact is not considered within the operational phase of the LCA.

2.4 Energy Simulation

This study used dynamic simulation that takes under consideration fluctuating factors like weather, occupancy and internal loads. The energy model is an important component of this study, as it enabled a direct comparison of the base case building's carbon footprint with the improved design. Changes made in construction methods and materials impact building’s energy demand, and this is what the energy simulation is crucial to assess. Operational energy use (B6) was predicted for both design scenarios to make sure that operational emissions are accounted for in each LCA.

2.4.1 Overview of the Studied Building

The building analysed in this study is located at Redaregatan 29 in Oceanhamnen, Helsingborg, Sweden. The L-shaped building consists of seven floors above ground and a basement. It is primarily a residential apartment building, with a small commercial area occupying approximately 2% of the building total area on the ground floor. The site plan of the building is presented in Figure 2.3.

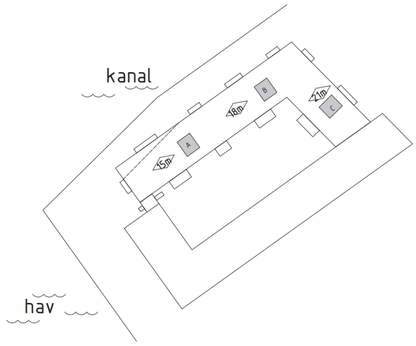

Figure 2.3: Site plan of the building

Several different exterior wall types were designed, among which two are used predominantly: one featuring brick cladding and the other utilizing slate panels. The basement height is 3.0 meters, the ground floor height is 3.3 meters, and the height of the remaining floors is 2.9 meters. The district heating was used as the heat source, and FTX was used as the exhaust system. A solar system was employed, with 100 m^2 photovoltaic (PV) panels installed on the roofs of the fifth and sixth floors to partially cover the property's electricity consumption. General information of this building is shown in Table 2.2.

2.4.2 3D Modelling and Geometrical Inputs

For purposes of the energy simulation, two buildings planned for Etapp 2 were modelled in Rhino 7. The first building, which has already been constructed, was modelled in high detail, as it is the main subject of this study. The second building, which is still in the plan phase, was modelled in a simplified form. Although not yet built, it was necessary to include this second structure in the model to accurately assess the impact of its adjoining wall on the thermal performance and energy behaviour of the existing building, under the assumption that it will be constructed according to the current plans.

In this model, interior walls and thickness of building components were omitted. Each floor of the analysed building was modelled and divided into two separate heating zones based on different exterior wall types. From the ground floor to the sixth floor, all areas, with the exception of staircases, were assigned a heating schedule. The basement and the staircases were modelled with a no-heating schedule. As a result, the model included 20 zones and assumed adiabatic conditions for the building during the planning phase.

The window-to-wall ratio (WWR) for each façade orientation, including the area of the balcony doors, was calculated based on the building's elevation drawings. The resulting WWR values are as follows: 0.30 for the northwest facade, 0.20 for the southeast facade, 0.35 for the southwest facade and 0.28 for the northeast facade.

Solar system was also modelled in this simulation, comprising 48 PV panels divided into two orientations. 37 PV panels facing southwest, and the remaining panels facing southeast.

The 3D model and the energy model input parameters are shown in Figure 2.4 and Table 2.2.

Figure 2.4: 3D model of building

Table. 2.2: General values and GH script values for the building

Description	General value	GH script value	Unit
Number of apartments	57	-	-
Gross floor area (BTA)	5791	5774	m^2
Heated floor area (A_{temp})	5162	5095	m^2
Basement area	380	396	m^2
Glazing area	837	955	m^2
Slate envelope area	371	598	m^2
Brick envelope area	1318	1846	m^2
Roof area	836	1139	m^2
Overhang area	81	80	m^2
Photovoltaic panels area	100	98	m^2

2.4.1 Tools and Plugins Used

Rhinoceros 3D and Grasshopper (GH) plugins included Ladybug (LB), Honeybee (HB) and ClimateStudio (CS) were used to create a detailed energy model of the building. These tools allowed for precise control over building's geometry and energy inputs.

2.4.3 Energy Inputs and Simulation Parameters

The thermal conductivity of individual materials and the overall thermal transmittance (U-value) of the building constructions were considered in the energy simulation. The construction and material specifications were modelled using architectural plans, energy calculations and technical drawings provided by PEAB and Åkermans Ingenjörsbyrå. A detailed overview of the materials and their properties can be found in Table 2.3.

Table 2.3: Input construction detail

Building parts	Thickness [mm]	Material	Thermal conductivity [W/mK]

Exterior wall	**Brick façade**	108	Brick	0.889
		32	Air gap	0.667
		80	Glass wool	0.030
		9.5	Wind barrier	0.580
		170	Glass wool	0.037
		45	Glass wool	0.037
		13	Gypsum board	0.159
		13	Gypsum board	0.159
		U-value [W/m²K]		0.130
	Slate façade	15	Slate panel	1.450
		25	Air gap	0.667
		50	Glass wool	0.030
		9.5	Wind barrier	0.580
		170	Glass wool	0.037
		45	Glass wool	0.037
		13	Gypsum board	0.159
		13	Gypsum board	0.159
		U-value [W/m²K]		0.150
Roof		40	Green roof (Sedum vegetation)	0.090
		4.4	Waterproofing membrane	-
		20	Rock wool	0.030
		370	EPS	0.037
		0.2	Plastic vapor barrier	-
		220	Concrete	1.950
		50	Precast concrete slab	1.950
		U-value [W/m²K]		0.090
Basement wall		5	Waterproofing membrane	-
		200	Drainage insulation	0.039
		250	Concrete	1.950
		U-value [W/m²K]		0.110
Plate on ground/ Basement floor		20	Timber flooring	0.023
		200	Concrete	1.950
		0.3	EPS	0.030
		0.2	Gravel	-
		U-value [W/m²K]		0.110
Overhang		20	Timber flooring	0.023
		220	Concrete	1.950
		50	Precast concrete slab	1.950
		300	Glass wool	0.037

	11	Metal cladding	215.000
	U-value [W/m^{2}K]		0.110
Window	35	Three-glass window	0.169
	U-value [W/m^{2}K]		0.880
Intermedia floor	20	Timber flooring	0.023
	220	Concrete	1.950
	50	Precast concrete slab	1.95
	U-value [W/m^{2}K]		0.85

The default occupancy, lighting, and equipment schedules from Honeybee were applied in the energy simulation. Internal loads, including people density,   lighting density, equipment density and the designated heating period, were defined according to *Boverkets föreskrifter och allmänna råd (2016:12)*(Jonfjard, n.d.). The assumptions are as follows:

- Occupancy schedule: ApartmentHighRise OCC_APT_SCH
- Lighting schedule: ApartmentHighRise LTG_OFF_SCH_2013
- Equipment schedule: ApartmentHighRise EQP_OFF_SCH_2010_2013
- Occupant density: 0.023 persons/m² A_{temp}
- Lighting power density: 2.5 W/m² A_{temp}
- Equipment power density: 3.0 W/m² A_{temp}
- Heating period: 14 hours/day, 7 days/week, 52 weeks/year

The heating setpoint temperature throughout the building was established at 21°C in line with standard comfort conditions. District heating was selected as the primary heating source, with a heat pump system applied in the modelled coefficient of performance (COP) of 4.2. No cooling systems were installed on the rooms, therefore, no cooling setpoint or cooling schedule was applied. The domestic hot water (DHW) was added directly to the final energy consumption with the same number form energy calculation provided by PEAB.

The building's total energy consumption included not only the simulation results but also additional factors such as airing through openable windows, hot water circulation (VVC) losses and losses related to control and regulation systems. These elements were incorporated based on the official energy calculation.

Solar energy production was simulated separately using Honeybee's photovoltaic modelling capabilities and the rated efficiency is 23%. Property-related energy consumption - including the operation of fans, pumps, outdoor and indoor lighting in common areas and elevators - was modelled using a simplified, consistent weekly schedule. This schedule was designed based on the values provided in the PEBA's energy calculation.

2.4.4 Method Verification

As a verification of the method, the results of the energy simulation were benchmarked with the building's Energy Performance Certificate. After converting units to kWh/m²/year A_{temp}, the simulated energy demand was compared with the values outlined in the official documents to validate the model's performance.

2.5 Life Cycle Assessment for the Building

The building's life cycle assessment (LCA) was conducted using Brimstone and several custom components developed based on the Brimstone's framework, a plugin for the Grasshopper visual script environment. Brimstone enables data retrieval from Boverket's Klimatedatabas via API access or file import and also allows users to manual input data for new material. This plugin facilitates the integration and processing of LCA data directly within the Grasshopper environment. The life cycle stages are defined by EN 15978 and EN 15804 (*PN326-BRE-EN-15978-Methodology.Pdf*, n.d.), (*BRE-EN-15804-A1-PCR-PN-514--Rev-2.0.Pdf*, n.d.).

The climate report for the building focuses solely on the A stage of the life cycle. It does provide important information about initial embodied carbon, however, does not account for the broader, long-term environmental impact of the building. In this study, the life cycle analysis is extended to include the B and C stages. The B stage, in particular, is more dynamic as it covers the operational phase, including energy usage, maintenance and any adjustments that occur over the building's lifespan. That stage varies with the changes implemented to the building's design. All of the cradle to grave stages are considered in this study to assess the building's environmental impact across its entire life cycle.

Due to limitations in the calculation and the absence of certain detailed construction drawings, not all materials listed in the climate report provided by Bygg Bostad Syd were considered. Materials were excluded if they were not represented in the available construction drawings and if their *share of total climate impact A1-3+A5 per resource* was less than 1%, according to the climate report. Moreover, although the climate report outlined a broad system boundary that included various components categories, some of these categories could not be incorporated into the actual calculations due to missing database sources. In additional, while the climate report referenced numerous resources from various database, some of these resources still did not have corresponding environmental product declarations (EPDs) with matching global warming potential (GWP) values for A stage. For such cases, stage A data from Boverket's Klimatedatabas was used as a substitute, while data from stage B and C was replaced with information from similar products that have complete EPDs. To benchmark the climate impact results against the climate report, the total climate impact of the A stage aggregated materials was compared with the number illustrated in the climate report.

2.5.1 LCA Workflow and Calculation Tools

In the building-related components life cycle assessment (LCA) calculation focused exclusively on global warming potential (GWP) to evaluate the building's embodied carbon. The analysed model was derived from the same Honeybee (HB) model of energy simulation, which was deconstructed into 20 rooms, each retaining its faces properties. These rooms were categorized into four groups based on their construction characteristics: surrounding building, brick envelope, slate panel envelope and basement. Different materials were assigned to the respective constructions associated with each category, and the rooms were subsequently reassembled into a new model for input into the Brimstone calculation. After specifying the thickness, density, thermal properties and GWP-total values for each material, the LCA calculation was performed.

2.5.2 LCA for B6 Stage

The B6 stage respects the operational energy use associated with the normal operation of the building during the reference study period, including all energy required by building related technical systems, in accordance with EN 15978 and EN 15603:2008 (*PN326-BRE-EN-15978-Methodology.Pdf*, n.d.). In this study, energy simulation served as the basis for calculation operational energy use, providing detailed estimates for district heating and electricity consumption.

To enable comparison with the energy calculation provided by PEBA, the Energy Performance Certificates (EPCs) calculation was utilized, as it offers a standardized approach to estimating building energy performance. The energy simulation results were categorised into four groups, including space heating, domestic hot water (DHW) heating and property electricity (with electricity for pumps and fans, and property lighting). This presentation of energy simulation results was based on the actual conditions of the studied building and the principles outlined in the Standard assessment Procedure (SAP), which forms the basis for calculation EPCs. Energy consumption from household lighting and electrical equipment was excluded from the analysis. For the carbon emissions calculation, a regional energy supply weighted emission factor of 0.037 kg CO_2-eq./kWh was applied for electricity and 0.056 kg CO_2-eq./kWh for district heating, which remained consistent over the life cycle. The B6 input values were based on energy simulation results calculated for 50-year life span.

2.5.3 Databases

The GWP-total values and data sources from the climate report were used as a benchmark for environmental product declarations (EPDs) selection. The data were categorized into three sources: the Boverket's Klimatedatabas, the Byggsektorns Miljöberäkningsverktyg (BM) database, and individual EPDs from other external databases. The majority of A stage data for the materials in the climate report was obtained from Boverket's Klimatedatabas.

The functional unit (FU) of each material was standardized to kg CO_2-eq./kg, which consistent with the FU used in Boverket's Klimatedatabas, prior to entering the data into Brimstone. The conservatively A1-A3 (product stage) value, along with generic construction process stage values (A4 and A5), were accessed from Boverket's Klimatedatabas and used as input. If a material uses an individual EPD, its conservatively A1-A3 values were adjusted with a 25% mark-up based on standard practice (Thrysin, n.d.). For the use stage within 50-year life period (B2 to B5: maintenance, repair, refurbishment and replacement), data from the BM database were prioritized. This database applied a customized material lifespan rather than using the standard material lifespan values provided in individual EPDs. The specific lifespans used for different material categories related to calculation were detailed in Appendix A. If these values were unavailable, the corresponding data from individual

EPDs were employed. For the end-of-life stage (C stage), all values were taken directly from the corresponding EPDs.

It was important to note that the majority of materials included in simulation was equal to or exceeded the analysis period and thus were not modelled for replacement. An exception was the selected PV panel, which had a declared life cycle of only 25 years according to its EPD. Therefore, this material was the only one considered for repurchase and reintegration during 50-year analysis period.

2.5.4 Integration of Operational Energy (B6)

To calculate the operational emissions, the *electricity, Swedish mix* and *District heating, Swedish average* from the Boverket's Klimatedatabas was applied. GWP values of 0.037 kg CO_2-eq./kWh for electricity and 0.056 kg CO_2-eq./kWh for district heating, constant each year, were used for both conservative and standard scenarios.

In addition, excess PV power generation beyond building's property energy consumption was sent back to the grid creating negative carbon emission which should be considered as an independent part. The same GWP value of electricity used in operational energy (B6) was applied to quantify the net carbon reduction associated with the exported electricity, meaning -0.037 kg CO_2-eq./kWh for exported electricity.

2.6 Life Cycle Assessment for Non-Building Elements

This part of the life cycle assessment (LCA) focuses on non-building elements. This LCA can be called extended because it goes beyond traditional building-focused analysis, considering infrastructure, inner courtyards and green spaces. There is no widely adopted methodology for assessing these elements. The workflow used in this study is universal and could be implemented in other researches. The LCA of non-building elements was conducted according to EN 15978 (*PN326-BRE-EN-15978-Methodology.Pdf*, n.d.), using EPD data as the basis for calculations.

2.6.1 Non-building Elements

This life cycle assessment encompasses both the building-related components and the surrounding elements essential to its operation and functionality. Included in the non-building elements analysis are components such as surrounding pathways, inner courtyards, road infrastructure, green areas and the technical installations that directly support the building's use. The components were divided into main categories based on their function and structural characteristics and then further broke down into smaller groups according to their location within the building site. Figure 2.5 visually presents the division and what kind of data were examined for each component to quantify used materials.

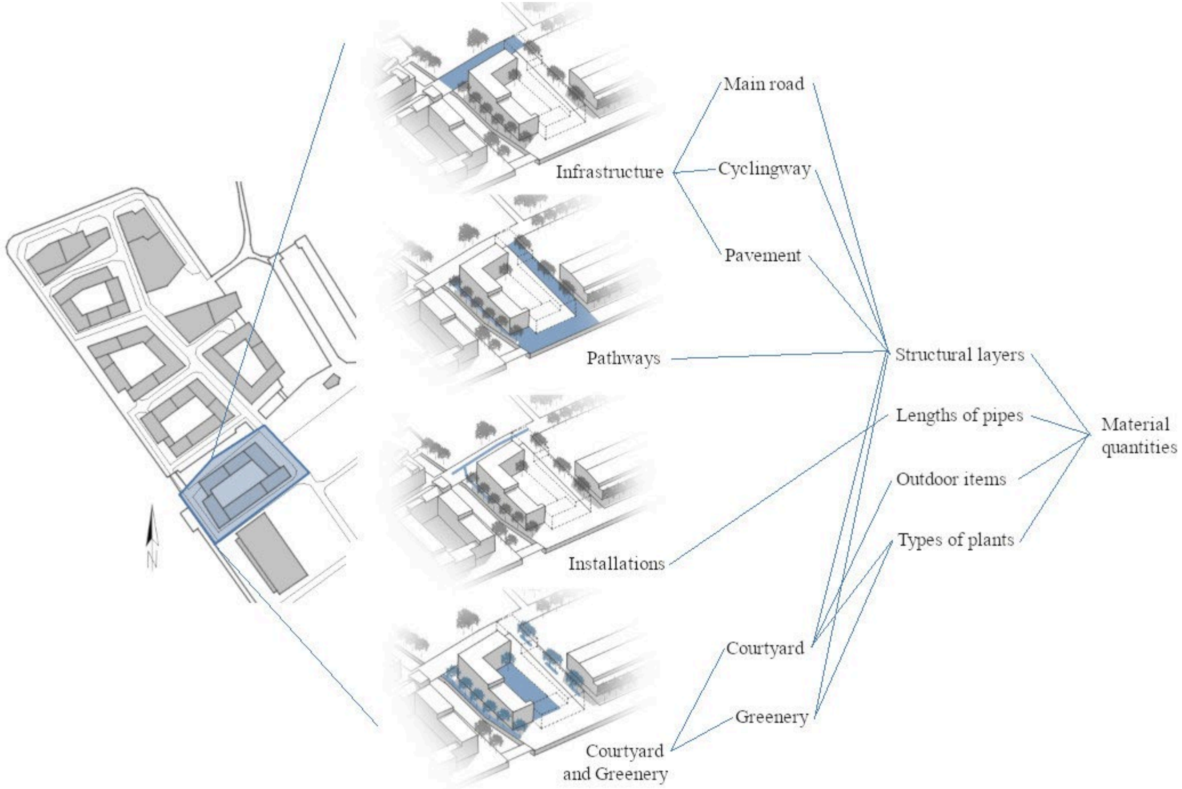

Figure 2.5: Division of non-building elements into main categories and subcategories with types of data utilized to quantify used materials.

The Infrastructure category included in the assessment covers the adjacent section of the main road, the cycling path and the pedestrian pavement to the building complex plot, taking into account all of their primary structural layers.

The term Pathways, as understood in this study, refers to all paved walkways surrounding the building complex. These areas are considered part of the supporting infrastructure and are included in the LCA with attention given to their full structural buildup and material composition.

The Installations assessed encompass all water, sewage, and electrical systems, including the tunnels and piping facilities vital to the building's operation. This covers the main external networks, such as the power grid and primary pipelines, that run along the length of the building complex plot and directly connect to the building's systems.

The Courtyard and Greenery category includes the architectural and structural design of the inner courtyard, incorporating both paved areas as well as majority of outdoor furniture. It also covers all planting areas located within the courtyard itself, as well as those surrounding the entire building complex. Due to complexity of the design, not all elements could be included into the assessment such as part of small architecture, some of outdoor fittings and lighting fixtures.

2.6.2 Inventory and Analysis of Existing Structures

In order to carry out a reliable life cycle assessment (LCA), the collection of accurate, detailed and comprehensive material data served as a fundamental starting point. The ability to precisely identify the types, quantities, and characteristics of materials used throughout the built environment is essential for ensuring the credibility and precision of environmental impact calculations. This data forms the basis for evaluating the embodied carbon and other environmental impacts associated with various construction elements.

In order to carry out a reliable LCA, the collection of accurate material data is a fundamental starting point. The base of every calculation is precisely identified types, quantities and characteristics of the materials used on the site.

To gather the necessary data, the primary focus was placed on examining technical documentation. Architectural plans, structural sections and installation drawings were carefully reviewed to identify material types, construction layers and how different components were assembled. A site visit was also conducted to better understand certain material applications. The bill of materials from neighbouring Etapp 1 of Oceanhamnen was also studied. Knowing the constructions similarities between Ettap 1 and Etapp 2 within for example shared infrastructure, the documentation helped to fill some lacking information on materials used in Etapp 2. It provided detailed data on structural layers and volumes used for roads, pavements and planting areas.

These sources were used for estimating the types and quantities of materials that appeared in the site. In certain cases where specific data was still missing or not clearly defined, reasonable assumptions must have been introduced. In these instances, standard construction practices or typical material compositions commonly used in similar projects were applied to fill the data gaps. That allowed to avoid underestimations resulted from omitting some of the structures.

Each material was quantified in terms of its coverage area, volume, thickness of the layer, length and diameter (pipelines) and weight. The weight was determined either by using the standard density values for the material or, when available, by referencing the density data provided in the respective EPD. The origin of data for each analysed element is summarized in Appendix B, highlighting the documentation used in each case.

2.6.3 Transport Emissions Modelling (A4, C2)

The transport stages (A4 and C2) were calculated using both contextualized and generalized methods. EPDs usually provide standardized transport values. A typical representative scenario is based on assumptions about transport distance, vehicle type and fuel consumption. In this study, transport emissions were also calculated manually using the EN 15978 standard method (*PN326-BRE-EN-15978-Methodology.Pdf*, n.d.), allowing for a customized scenario that reflects the specific conditions of the Oceanhamnen site, including actual distances and vehicle types.

To calculate the carbon footprint of a transport stage, three key indicators are required: the environmental impact of transport used, the distance travelled and the weight of the material being transported.

The Table 2.4 below presents the three means of transport used in the project, along with their associated environmental factors based on Global Logistics Emissions Council Framework v2.0 (*2019_GLEC_Framework_July_2022.Pdf*, n.d.).

Table 2.4: Types of transportation with related environmental factors.

Mean of transport	**Environmental factory [kg CO_2 eq./ton□km]**
Small lorry 7,5t	0,169
Lorry 22t	0,105
Railway cargo	0,028

The choice of transport was determined based on the maximum load capacity of the vehicle and the distance to be covered. Table 2.5 shows three transport methods calculated in the study. To build a realistic scenario, in some cases a combination of two transportation methods were used. For longer distances, railway transport was employed for the majority of the journey, while a lorry was used to complete the final part of the journey to the building site. However, to give a fair relation to the EPD generalized calculations, which are based on use of lorry only, another contextualized scenario was evaluated assuming same mean of transport. This scenario was created solely in purpose of comparison. In all the overall LCA calculations of non-building elements presented in this study, realistic contextualized transport method was applied.

Table 2.5 *Transport scenario methods described with the source and type indicated.*

Transport scenario	**Transportation methods**	**Source of environmental impacts**	**Type of scenario**
Realistic	Rail + lorry	GLEC v2.0	Contextual
Generalized	Lorry	EPDs	Standardized
Comparable	Lorry	GLEC v2.0	Contextual

The distances for the A4 stage varied between the material and were generally calculated from the closest production site of the material to the building site. However, in cases where the documentation specified a particular material, the distance was calculated based on the location of that specific production site to the building site. The distance for the C2 stage was calculated from the building site to the nearest disposal facility and it was assumed to be 10 km.

2.6.4 Carbon Sequestration from Vegetation

Because of lack of EPDs considering plants, different methods of calculation were employed based on found literature on the subject. Greenery contributes to CO_2 sequestration but also to CO_2 production, therefore the method was divided into assessing absorption and emissions. Plants planned for the building site were divided into 3 categories based on their size: trees, shrubs and small plants.

Absorption

Each category was assigned a yearly carbon absorption, see Table 2.6, (EcoTree, n.d.; Hall & Ingram, 2015),(*Estimation on Individual-Level Carbon Sequestration Capacity of Understory Perennial Herbs | Journal of Plant Biology*, n.d.). Total absorption was calculated for the life cycle period of 50 years. These values were then multiplied by the amount of plants in each category, see Appendix B.

Table 2.6: Main plant groups with their assumed carbon absorption

Type of plant	**Yearly carbon absorption [kg CO_2 eq./year/plant]**	**Total carbon absorption over 50 years [kg CO_2 eq./plant]**
Tree	20	1000
Shrub	0,5	25
Small plant	0,003	0,075

Emissions

The occurring emissions are associated with activities like production, planting, fertilizing and eventual disposal. Based on results from the study on park trees in Swedish cities (Lind et al., 2023; Tommila et al., 2024) the emission factor was introduced for each category. It was defined as a percentage of the total carbon absorption of a plant over a 50-year lifespan, see Table 2.7. The total emissions per plant were calculated and then multiplied by the amount of plants within the site.

Table 2.7: Main plant groups with their assumed carbon emissions

Type of plant	**Emission factor [%]**	**Total carbon emissions [kg CO_2 eq./plant]**
Tree	2	20
Shrub	1	0,25
Small plant	1	0,00075

Total carbon sequestration from greenery was calculated by summing absorption and emission outcomes.

2.6.5 LCA Data Gaps and Assumptions

Due to the innovative nature of this study, certain simplifications and limitations are occurring. The lack of established data sources and the absence of a standardized workflow for assessing non-building elements have presented key challenges. As a result, the main limitations of this extended LCA are outlined below.

The primary major issue appears in the form of the absence of a single complete database for environmental product declarations (EPDs) relating to non-building elements. This required for manual search for individual EPDs. The most used databases were Environdec (*EPD Library | EPD*

International, n.d.), EPD-Denmark (*EPD Databasen*, n.d.) and EPD Norway (*EPD Norge - Forsiden*, n.d.). In cases where region-specific EPDs for the Scandinavian context were unavailable, the geographical area was expanded including broader European data. When no EPD could be found for a specific material, the data for materials with a similar function or production were used.

Another limitation concerns missing stages in some of the EPDs. The A5 - construction stage, particularly for soil-related materials, was often excluded. This omission resulted in gaps in data for emissions related to the installation processes, potentially leading to a slight underestimation of the total embodied carbon for these materials. Similarly, the B stages (use phase) were frequently missing from the available EPDs. Some of them included only B1, while others lacked B-stage data entirely. The absence of B-stage data was often justifiable for materials that require no maintenance or replacement throughout their lifecycle. These stages were commonly omitted due to their relatively low impact or because they are highly dependent on factors such as the specific situation, location, and climate.

What was not taken into account of non-building elements calculations are some of the technical fittings classified under Installations category and parts of design of the Courtyard – minor outdoor fittings, lighting fixtures and small architecture elements. These omissions are not expected to have an impact on the results as their carbon footprint is relatively low.

2.7 Earthworks Emissions Estimation

Earthworks refers to the excavation of soil and the associated processes involved in preparing the site for construction. This stage is treated as a separate category in the study. However, while earthworks are related to the construction phase, they are not included in the A5 stage of the LCA materials, as they are not directly associated with the materials themselves but rather with the preparation of the site.

The calculation of GWP associated with earthworks was based on EN 15978 (*PN326-BRE-EN-15978-Methodology.Pdf*, n.d.), focusing primarily on fuel emissions. The category includes the operation of excavation machinery and the transportation of excavated soil to the disposal site. The earthworks are related to both building and non-building elements. The Table 2.8 presents the volume of soil needed to be extracted for each component.

Table 2.8: Main components with associated volumes of soil to be extracted

	Name of the component	**Volume of extracted soil [m^3]**
Non-building related	Infrastructure	500
	Pathways	1071
	Installations	68
	Courtyard and Greenery	630
Building related	Basement	1267
	Foundation	112

The calculation process was divided into two parts. The transport component was calculated using the same method as for the transport C2 stage. The operation of excavation machinery was calculated by multiplication of four key factors: the efficiency of the excavator [m^3/h], the duration of its operation [h], the fuel consumption [l/h] and the environmental fuel factor [kg CO_2 eq.]. The efficiency of the excavator was assumed to be 50 m^3/h (*pdfPerformanceHandbook49.Pdf*, n.d.) and the fuel factor to be a standard value of 2,6 kg CO_2 eq. (*Calculating-CO2-Emissions-from-Mobile-Sources.Pdf*, n.d.).

2.8 Functional Units and Result Normalization

The results were expressed in several functional units, allowing for a broader and more realistic comparison with other data. The functional units used were:

- per the building complex [kg CO_2 eq]: this metric takes into account all the quantities of materials used in the case study design, providing a direct representation of the environmental impact based on the specific materials incorporated into the building complex.
- per BTA [kg CO_2 eq/m^2]: this expression divides the carbon emissions values by the Building Total Area (BTA), providing a more standardized measure of environmental impact relative to the building's size.
- per area of footprint [kg CO_2 eq/m^2]: this functional unit considers the area associated with each category, providing a measure of the carbon footprint relative to the surface area covered by the material. For example, carbon emission of pathways is divided by the area of pathways. That way of presenting the values shows the carbon density of each structure.

2.9 Low-Carbon Structural Design

Improving a building can be conducted by focusing on different aspects of its design such as aesthetics, functionality or contextual integration. However, this study focuses solely on the decarbonization of the building, prioritizing these strategies that impact the carbon footprint, making sure that sustainability is the core of the process. The goal is to select low-carbon materials and construction methods without compromising overall function and performance.

The goal of analysing the improvement options is to evaluate the building complex that is a part of a city district which was designed to be carbon efficient. This determines whether it achieves this goal or how it can be achieved. By exploring different design options, other more effective carbon reducing strategies though materials and structure system could be found. The effects may highlight more efficient designs and lessons to be learned while planning the next stages of the district.

2.9.1 Original Structural System: Concrete-Based Design

The building employs a shear wall structure, in which the reinforced concrete walls replace the traditional beam system for bearing both vertical and horizontal loads. This system comprises longitudinal and transverse shear walls that transfer loads to the foundation. However, most envelopes structures were still supported by a beam system which offers improved construction speed and efficiency. In the absence of detailed structural system diagrams, assumptions were made based on the original construction drawings, shown in Figure 2.6, and the specific details about the above structures were demonstrated in the Appendix C.

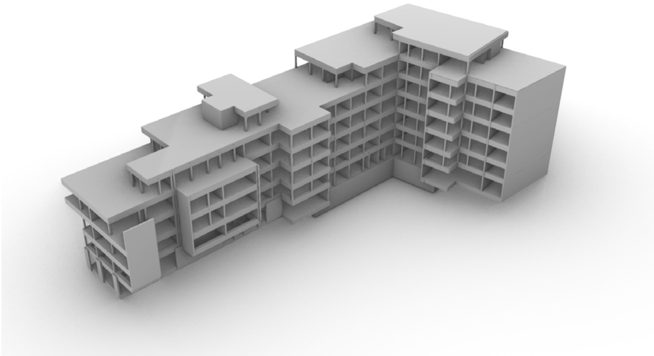

Figure 2.6: the overview of original structure system, including foundation, basement, exterior structure, shear wall structure and slabs.

The reinforcement ratio for different concrete grades in each construction element was difficult to determine due to the limited availability of construction drawing and insufficient technical knowledge. To ensure consistency and reasonable assumptions, all reinforcement ratios were recalculated using the formular which was found in EN 1992-1-1 (*En.1992.1.1.2004.Pdf*, n.d.). A sample reinforcement calculation was presented in the Appendix D.

2.9.2 Alternative Structural System

A hybrid timber-concrete system was adopted, in which the wooden structure replaced most of the original concrete structure system. The designed principles for the redesigned hybrid system were referenced the Moholt 50|50 project (*Moholt Timber Towers by MDH Arkitekter*, 2017), a student housing building in Trondheim, Norway; the T3 Minneapolis (*T3 Minneapolis*, n.d.), an office building in Minneapolis, the USA; and TRÄ8 (*Flervåningshus Trä8*, n.d.), a glulam-based beam system.

Retained structure

To simplify the redesigned structure system and ensure structural stability, the structure of foundation, basement and ground floor were retained. In addition, the shear wall of the staircases was also retained as the core.

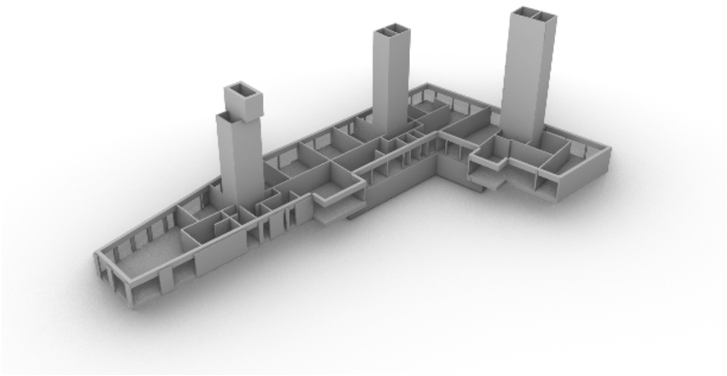

Figure 2.7: The retained structure

Slab modifications

The first structure design modification toward a hybrid system that was made to the slab structure, since slabs account for a significant proportion of total material usage. In the redesigned system, only the concrete construction layers were replaced with timber elements. To reduce material consumption, a 6-meters-span cross-laminated timber (CLT) rib panel was selected to replace intermedia floors and roof construction. For the overhang slabs, improved load-bearing property was required using reinforced CLT rib panels. Figure 2.11 emphasizes the CLT floor and roof slabs in the building.

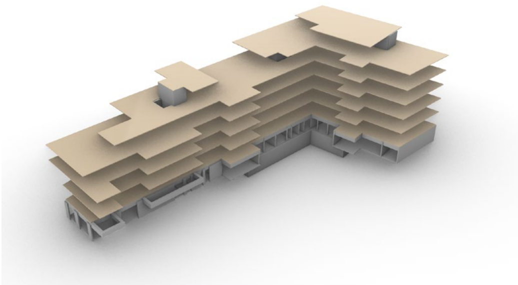

Figure 2.8: Floor and roof CLT slab changes

Structure modifications

The redesigned beam-column structure system composed of glue-laminated timber (GLT) beams and laminated veneer lumber (LVL) columns, replacing the original shear wall structure. In this system, the loads from the slabs are transferred to the beam and subsequently the cumulative load is transferred to the supporting columns and accumulated. Therefore, columns on each floor bear varying degrees of loading, their dimension should ideally be designed individually. However, to simplify the model, an average column dimension per floor was applied. The new structure system was shown in Figure 2.12.

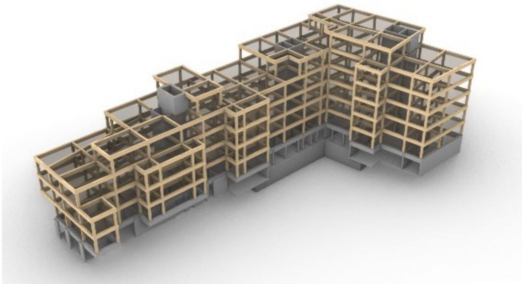

Figure 2.9: GLT beams and LVL columns changes

Structure dimension

The dimensions of the structural system were adjusted based on the TRÄ8 and the Calculatis® calculation by Victor (Tran & Delorme, 2023). The rib slab panels used were shown in Figure 2.13. The final structural dimensions are summarized in Table 2.9.

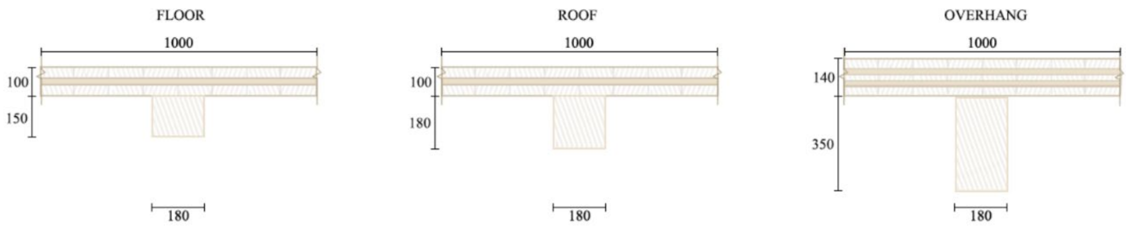

Figure 2.10: CLT rib panel slab size

Table. 2.9: dimensions of the alternative structural system and the new construction thermal transmittance (U-value)

Property		**Values**
Dimension of cross sections	LVL Columns	250 mm G 400 mm
	GLT Beam	320 mm G 600 mm
Intermedia Floor	CLT Rib Panel	250 mm
	Replaced constructed U-value	0.52 W/m²K
Overhang	CLT Rib Panel	490 mm
	Replaced constructed U-value	0.09 W/m²K
Roof	CLT Rib Panel	280 mm
	Replaced constructed U-value	0.10 W/m²K

Biogenic Carbon Accounting for Timber-Based Material

Specifically, the carbon emissions associated with the A and C stages of timber-based materials were not possible to compare individually with those traditional materials. According to EN 16485, the GWP values for timber products often show the negative carbon emissions of the module A1, due to the biogenic carbon naturally sequestered during tree growth, which remains stored in the harvested timber throughout its A and B stages of its life cycle (Achenbach et al., 2018). For the end-of-life stage (C stage), waste processing phase (C3) was calculated using the default scenario in most EPDs, which assumes 100% incineration with energy recovery. Under this scenario, the previously stored biogenic carbon is released back into the atmosphere, effectively neutralizing the earlier negative emissions and highlighting the importance of accounting for the full life cycle.

2.9.3 Design Assumptions and Simplifications

The alternative structural system design was not comprehensively developed due to limitations in time and expertise. To shorten the time required for redesign, the connections between the new system and the remaining reinforced concrete elements were not fully corresponded to each other. The preliminary design of the new system was conservatively evaluated based on existing empirical dimensions rather than optimized engineering calculation. As a result, the new system was not designed to maximize material efficiency in the same way as the original reinforced concrete system, which has been engineered by structure professionals with performance and resource optimization in mind. For simplification purposes, components such as steel connectors, anchors, and linked elements, with small proportion compared to total material usage, were omitted during the design stage.

3. Results

The results of this study cover an overview of both the operational energy use of the building and GWP associated with materials and construction activities. This chapter is structured to first present energy performance outcomes, followed by the embodied carbon results of building and non-building elements. Data are reported both as absolute values and relative comparisons to better illustrate performance trends and the impact of alternative choices.

3.1 Energy Simulation

Table 3.1 compares the specific energy use (purchased energy) reported in the Energy Performance Certificate (EPC) with the energy simulation results for the two scenarios. The results indicated that the error margin between the simulated values for the original scenario and the EPC's specific energy use was within an acceptable range, typically below 10% of the number presented in PEAB's energy calculation, confirming the reliability of the calculation. Due to all other materials remained the same except for the replacement of the reinforced concrete structure, the differences in U-values across the different scenarios were negligible. As a result, the simulated energy consumption for district heating differed by only 0.1 kWh/m^2/year. The building with both original and alternative scenarios were classified as energy class C, which is the minimum energy class that complies with new building regulation.

Table. 3.1: *Comparison of specific energy need from Energy Performance Certificate and simulation results with original and alternative scenarios.*

Parameter		Energy Performance Certificate: specific energy [kWh/m^2/year A_{temp}]	Simulation with original structural [kWh/m^2/year A_{temp}]	Simulation with alternative structural [kWh/m^2/year A_{temp}]
District heating		23.8	29.6	29.5
Domestic hot water		25	25	25
Airing*		4	4	4
VVC**		3.9	3.9	3.9
Control and regulation losses		1	1	1
Heat pump		0.5	0.5	0.5
Fan		5.5	5.5	5.5
Other property electricity		3	2.9	2.9
Solar system	**Total production**	3.6	3.6	3.6
	Property consumption	2.1	2.5	2.5
	Send to Grid	1.5	1.1	1.1

Total specific energy* **	**64.5**	**69.9**	**69.8**

* Infiltration through openable windows

** Hot Water Circulation (VVC) losses

*** Unweighted energy use summaries of all parameters

The production of solar system was divided into two parts: the electricity used for property consumption and the electricity send to grid. In this studied building, property consumption included heat pump, fan and other property electricity. To calculate the share of solar production used for property consumption, the hourly solar system production associated to solar radiation intensity was subtracted from the hourly property consumption. Since the solar production in energy simulation was variable and did not fully align with the simulated property energy consumption, only 2.5 kWh/m^2/year of solar production was used in the building. The surpass electricity generated by the solar system, accounting for 1.1 kWh/m^2/year, was exported to the grid.

3.2LCA of the Building

This section introduces the LCA simulation results performed for the residential apartment building analysed, showing the total GWP emissions of building-related components in kilograms of carbon dioxide equivalent per building total area [kg CO_2-eq./m^2 BTA] as a functional unit. Detailed information about both original and alternative scenarios material was shown in Appendix E.

3.2.1 LCA of Original Scenario

Figure 3.1 indicates the carbon emission in the analysed building based on LCA modules. The highest impact in this building was the building materials (A1-A3) with 237 kg CO_2-eq./m^2 emission. The following impact was operational energy use (B6) with 158 kg CO_2-eq./m^2 emission, which deducted the energy produced by the PV system used within the property. The solar production sent to the grid (1.1 kWh/m^2/year) represented a net reduction of -2 kg CO_2-eq./m^2 emission, calculated using the regional energy supply weighted emission factor for electricity. The total GWP value was 453 kg CO_2-eq./m^2 of building's whole life cycle.

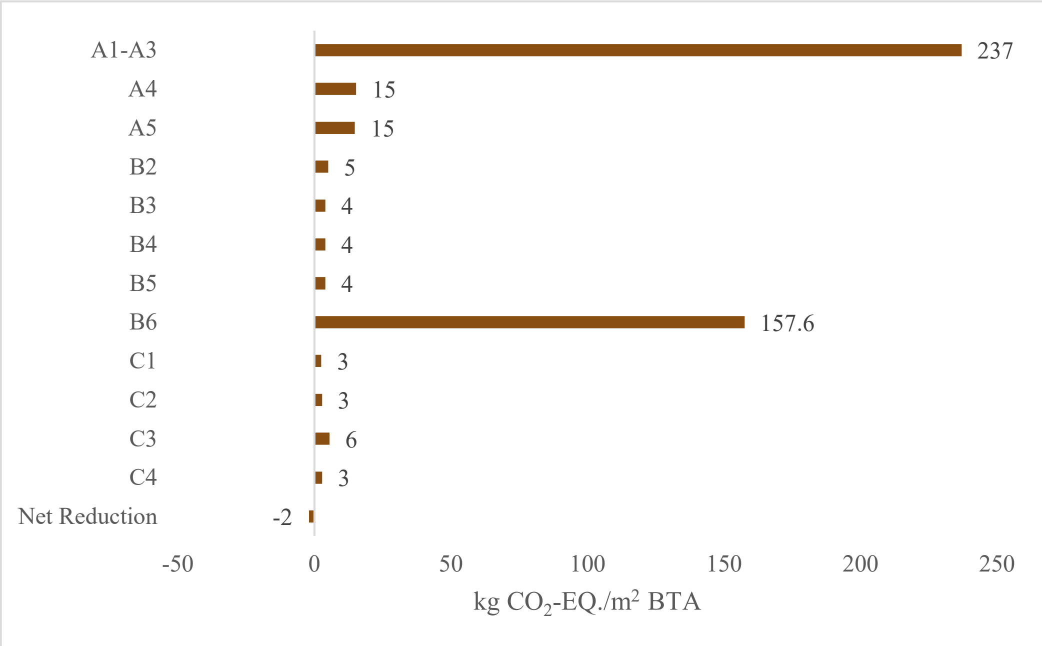

Figure 3.1: LCA calculation of original scenario, with 453 kg CO_2-eq./m^2 total GWP value.

Figure 3.2 compares the A stage carbon emissions between the calculation results and the climate report. This subset of materials modelled in the calculation (excluding newly added foundation, basement materials and PV panels) resulted in 235 kg CO_2-eq./m^2, accounting for 91% of the A stage reported climate impact. The additional emissions associated with the extended system boundaries (including foundation, basement and integrated solar cells) contributed a further 13% of the total A stage climate impacts presented in the climate report.

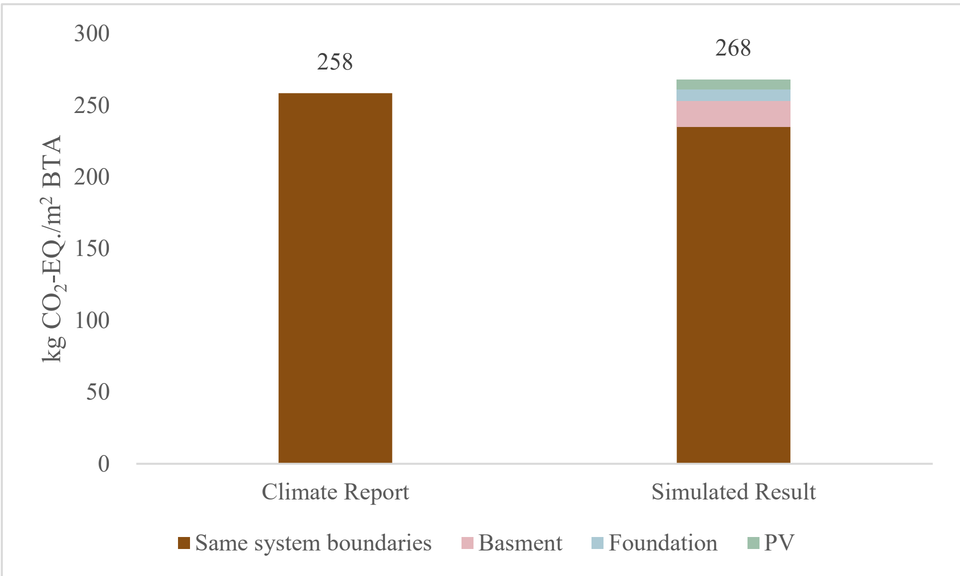

Figure 3.2: A stage carbon emissions of climate report and simulated results (original scenario)

All the building-relevant components were grouped into six categories: façade, basement, foundation, structure, slabs and others, as shown in Figure 3.3. In total, the building whole lifespan emissions accounted for 299 kg CO_2-eq./m^2.

The horizontal structure elements, slabs, which contained the largest quantities of concrete and rebar, had the highest impact. They contributed a total of 115 kg CO_2-eq./m^2 of which 111 kg CO_2-eq./m^2 occurred during A stage. In this category, 98% of the total emissions were associated with concrete, and 2% with rebar. In addition, the shear wall structure and external supporting structure were following, which together accounted for 77 kg CO_2-eq./m^2, with 76 kg CO_2-eq./m^2 attributed to A stage.

The climate impact from the C stage was negligible across all categories. This is partly due to C stage is not included in the system boundaries of some EPDs, and partly because many of the materials consumes less energy for deconstruction and demolition.

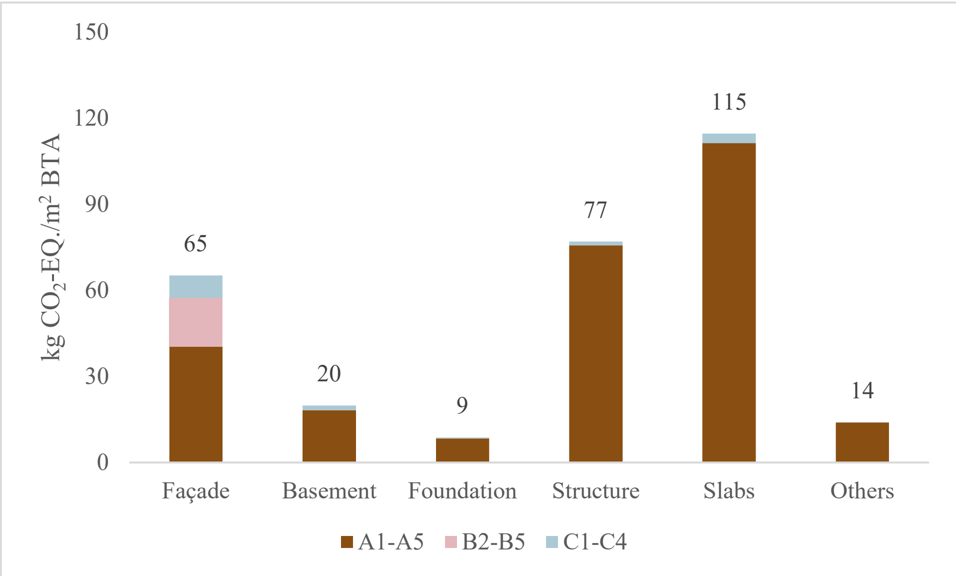

Figure 3.3: Carbon emissions of different categories (original scenario)

3.2.2 Alternative Scenario

After change the reinforce concrete structure to hybrid timber-concrete structure, a significant difference of LCA calculation was shown in Figure 3.4. As a large amount of timber productions were utilized, the emission of building material (A1-A3) was converted to a negative value with -115 kg CO_2-eq./m^2 emission, and the waste processing phase (C3) became the highest impact of this building with 228 kg CO_2-eq./m^2 emission. The building's whole life cycle climate impact emission was 316 kg CO_2-eq./m^2 which means a reduction by 137 kg CO_2-eq./m^2 (30 %).

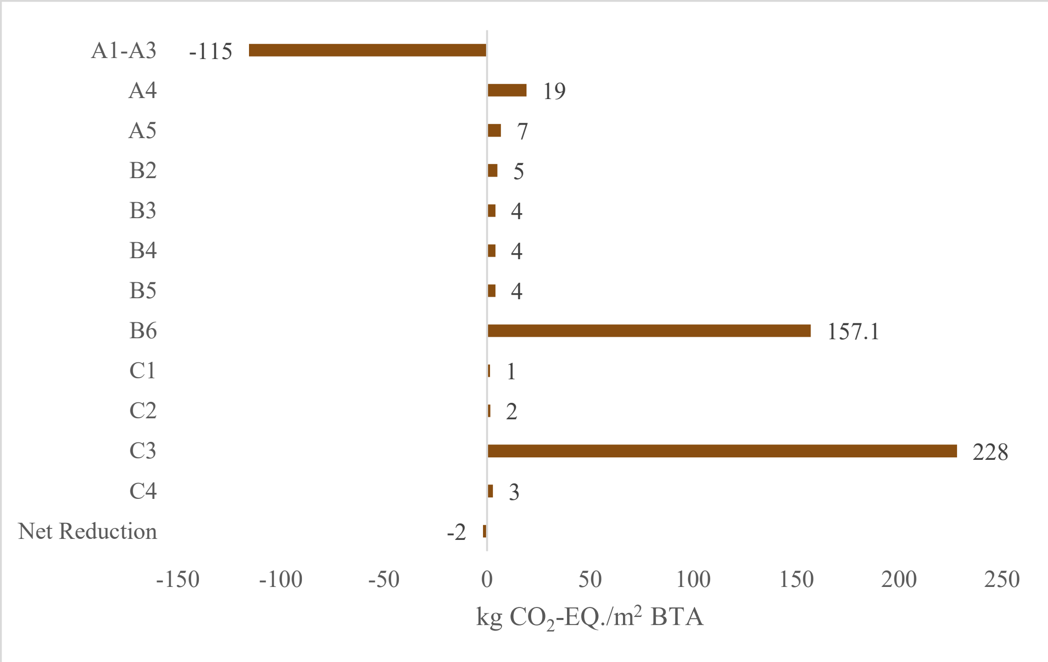

Figure 3.4: LCA calculation of alternative scenario, with 316 kg CO_2-eq./m^2 total GWP value.

Figure 3.5 indicates the total emissions across six categories. Consistent with the original scenario, the façade was the largest emission among all categories, while emissions from the foundation and basement also remained the same. In contrast, the total emissions from the structure and slabs showed a dramatic decrease, with 38 kg CO_2-eq./m^2 and 26 kg CO_2-eq./m^2 respectively. These values represent reductions of 51% and 80% compared to the original structure system.

Notably, The A stage emissions for structure and slabs were -41 kg CO_2-eq./m^2 and -114 kg CO_2-eq./m^2 respectively, while the corresponding C stage emissions were 79 kg CO_2-eq./m^2 and 139 kg CO_2-eq./m^2, respectively.

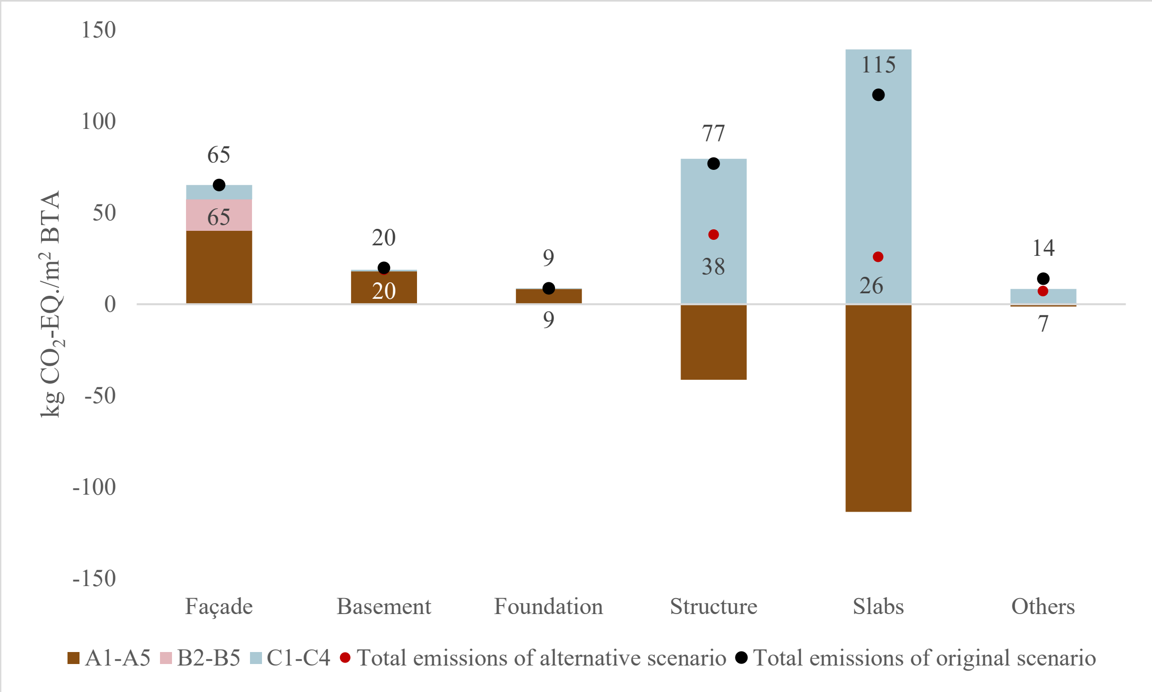

Figure 3.5: Alternative scenario total carbon emissions of different categories, compared with the original scenario.

To further demonstrated the influence of alternative structure system, the calculated GWP values for different stages of both timber-based materials and retained reinforced concrete materials of alternative scenario were exhibited in table 3.2.

Table. 3.2: The calculated GWP values for timber-based materials and reinforced concrete materials used in alternative structure system.

	A Stage [kg CO_2-eq./m²]	**Modules B2-B5 [kg CO_2-eq./m²]**	**C Stage [kg CO_2-eq./m²]**	**Cumulative GWP [kg CO_2-eq./m²]**
Timber-based materials	-214	0	227	13
Reinforced concrete materials	86	0	1	87
Combined total (kg CO_2-eq./m²)	-128	0	228	100

3.2.3 Structure System Comparison

To more precisely illustrate the changes in climate impact resulting from the structural system replacement, the results are summarized in Figure 3.6, which considered only the reinforce concrete and timber components from the structure, slabs and basement. Due to the significantly low climate impacts of timber products compared to reinforce concrete, the difference in emissions were considerable. The alternative structure system resulted in a 50% decrease in total emissions compare to the original structure system.

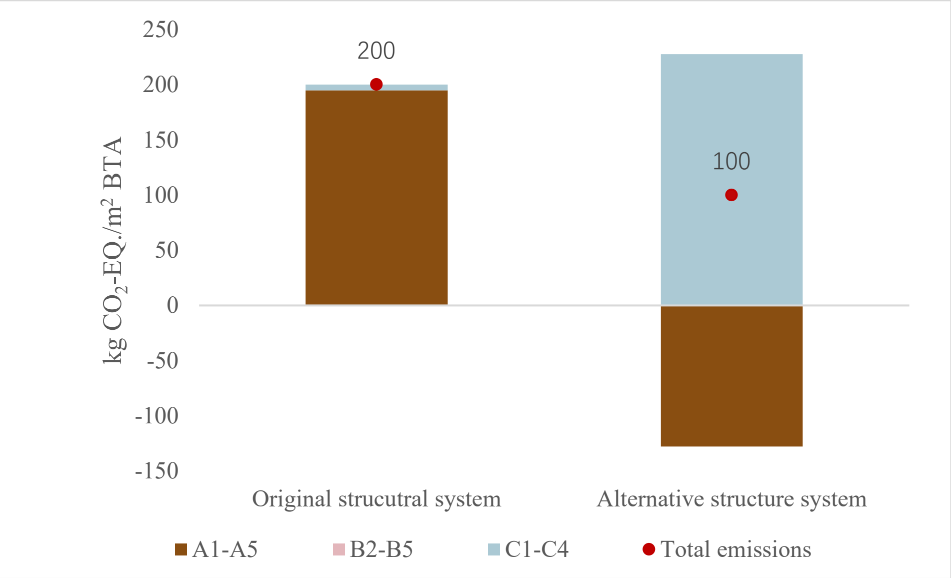

Figure 3.6: Comparison of two different structure systems of LCA emission

3.3 LCA of Non-building Elements

This section introduced results of non-building elements GWP assessment for each category. Detailed results for each material can be found in Appendix B.

3.3.1 Results within the Site

The results presented in this section are based on the total quantities of materials used within the analysed building site of Etapp 2. All calculated environmental impacts are expressed in terms of kilograms of CO_2 equivalent [kg CO_2 eq]. Presenting the results in this way, offers an insight into the emissions ratios specific to the project's context.

Percentage distribution of GWP values throughout the building site is presented in the Figure 3.7. The results show that Pathways has the highest impact, being 34% of the overall carbon footprint of non-building materials. The smallest part is related to Installations – 16%. The figure 3.7 presents the total GWP values associated with each category with break down into A, B and C stages of LCA. A stage- production - accounts for the majority of GWP. The B stage is almost negligible in most of the categories. However notably, an impactful negative value appears within the Courtyard and Greenery category. Total GWP of all of the non-building elements equals to 90069 kg CO_2 eq.

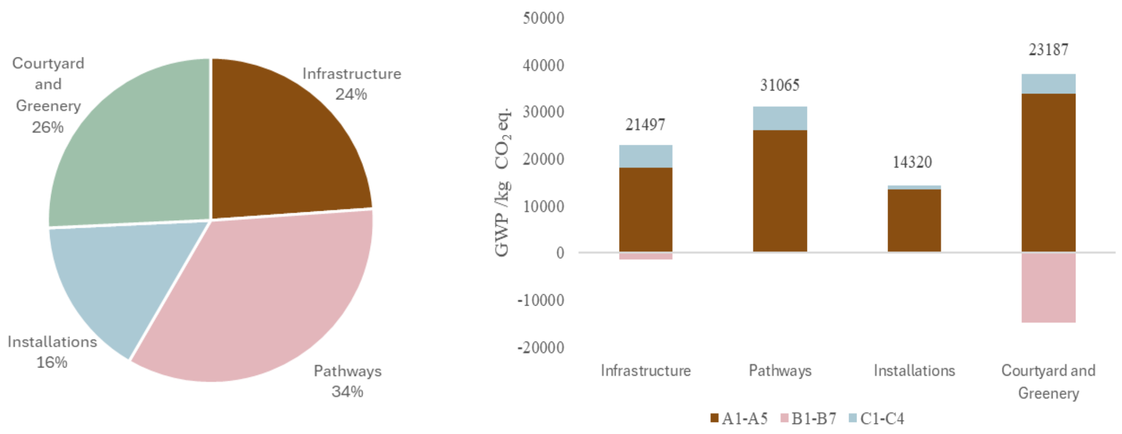

Figure 3.7: Total GWP of non-building elements within the building complex: percentage values to the left and absolute values to the right.

Figure 3.8 depicts total GWP values of the non-building elements divided further into subcategories. It can be observed that Main Road structure has the highest impact of Infrastructure category, and it equals to 9856 kg CO_2 eq. Pathways represent the highest value within the site - 31065 kg CO_2 eq. After Greenery was derived into its own category, Courtyard value now shows the carbon footprint related to materials used specifically in the area of the inner courtyard of the complex.

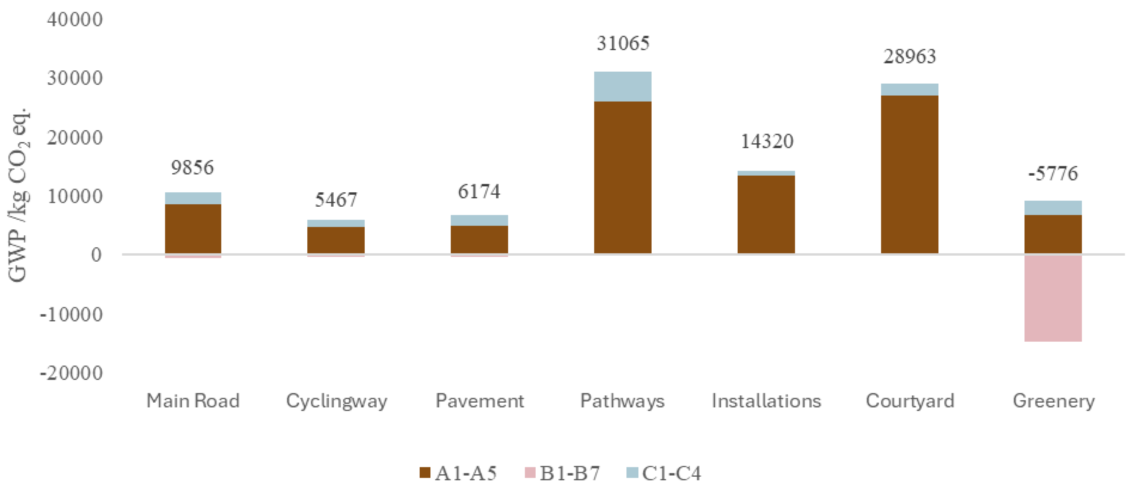

Figure 3.8: Total GWP of non-building elements within the building complex divided into subcategories

3.3.2 Carbon Density - Results per Area of Footprint

Figure 3.9 presents values normalized by footprint area of each subcategory giving the overall idea about the level of carbon density of the element. Clear highest value is associated with Installations – 86 kg CO_2 eq./m^2. Pathways, in contrast to total GWP values, represents one of the lowest result equal to 17 kg CO_2-eq./m^2. Greenery shows the lowest value of –15 kg CO_2 eq./m^2. Rest of the categories does not show much of the fluctuation.

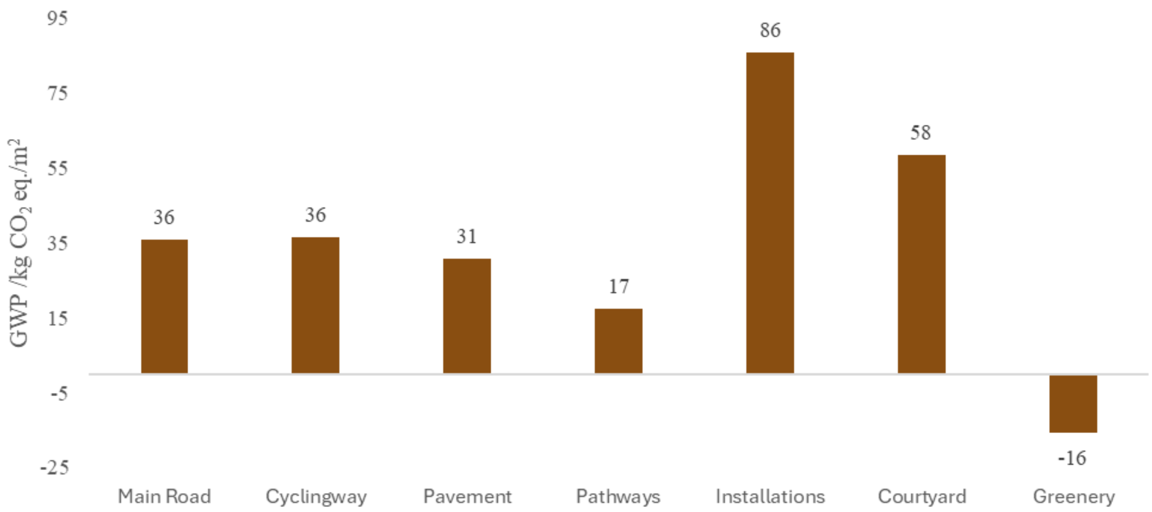

Figure 3.9: Carbon density expressed in kg of CO_2 eq. Per area of footprint of the category.

3.3.3 Results per BTA

Results shown in the Figure 3.10 are normalized by the BTA of the building for four main categories and divided into the stages of LCA. The values range from the 4 kg CO_2 eq./m^2. To 2 kg CO_2 eq./m^2, the highest being associated with Courtyard and Greenery and the lowest with Installations. Total GWP for non-building elements per BTA sums up to 16 kg CO_2 eq./m^2.

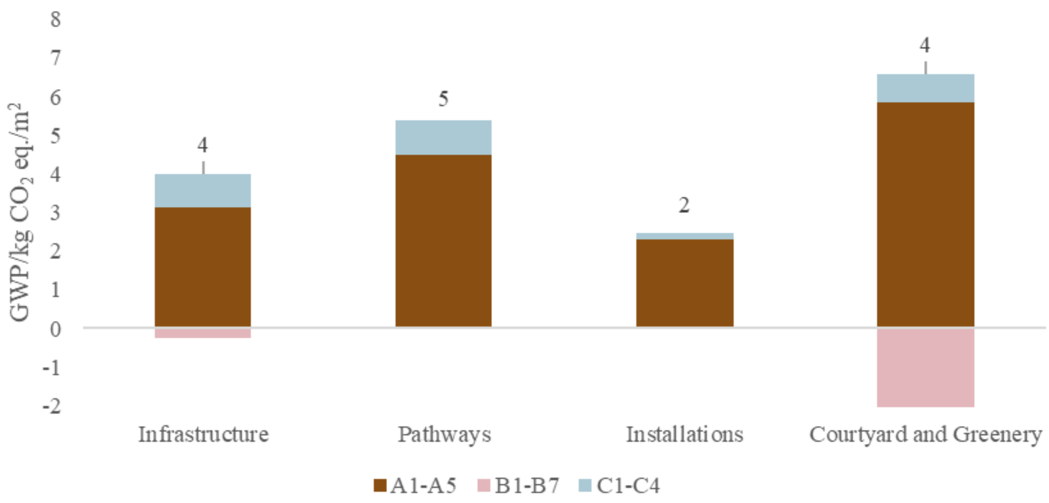

Figure 3.10: GWP per BTA of non-building elements main categories.

3.3.4 Transport Calculations/ Impact of Transport Scenarios

Following results are focused on transport stages of LCA - A4 and C2. Figure 3.11 shows the values in kg CO_2 eq. under three different transport scenarios: realistic, generalized and comparable. Across all categories, the comparable transport scenario consistently results in the highest emissions, most notably for Pathways (77 kg CO_2 eq.) and Infrastructure (53 kg CO_2 eq.). Installations contribute minimally to GWP under all scenarios, with values below 400 kg CO_2 eq. The realistic and generalized scenarios result in similar values with the generalized scenario slightly lower.

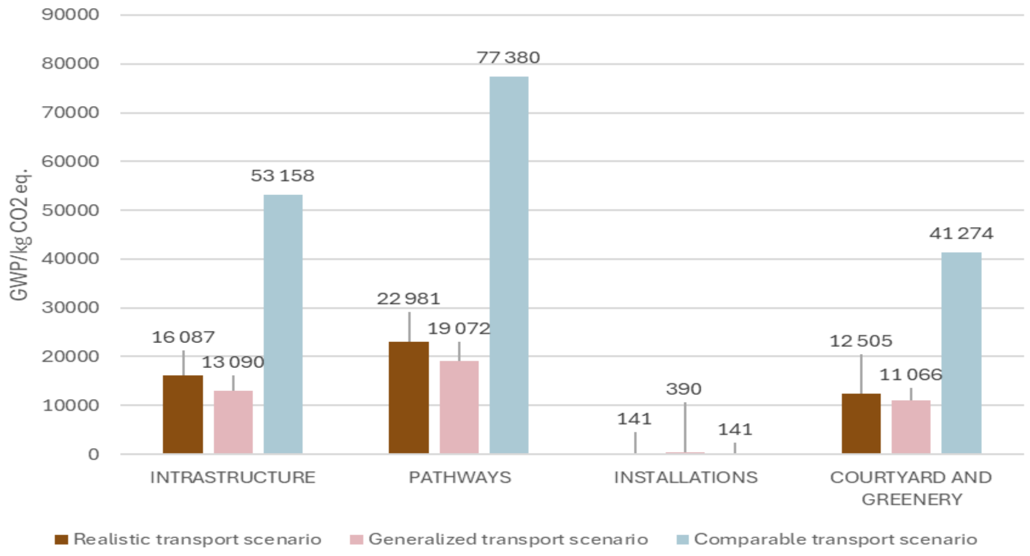

Figure 3.11: Impact of transport scenarios on transport stages of LCA

3.3.5 Earthworks

Figure 3.12 illustrates the CO_2 production [kg CO_2 eq.] associated with extrusion and transport stages of the category of Earthworks. Among all categories, the Basement has the highest combined emissions - 4165 kg CO_2 eq., while Installations show the lowest impact equal to 224 kg CO_2 eq. In all cases, both extrusion (pink) and transport (brown) stages contribute to total emissions with transport being slightly heavier factor. Earthworks emissions associated with non-building elements sum up to 7463 kg CO_2 eq., having a higher impact that building related earthworks values - 4535 kg CO_2 eq. Earthworks account for 1% of all carbon emissions in the building site.

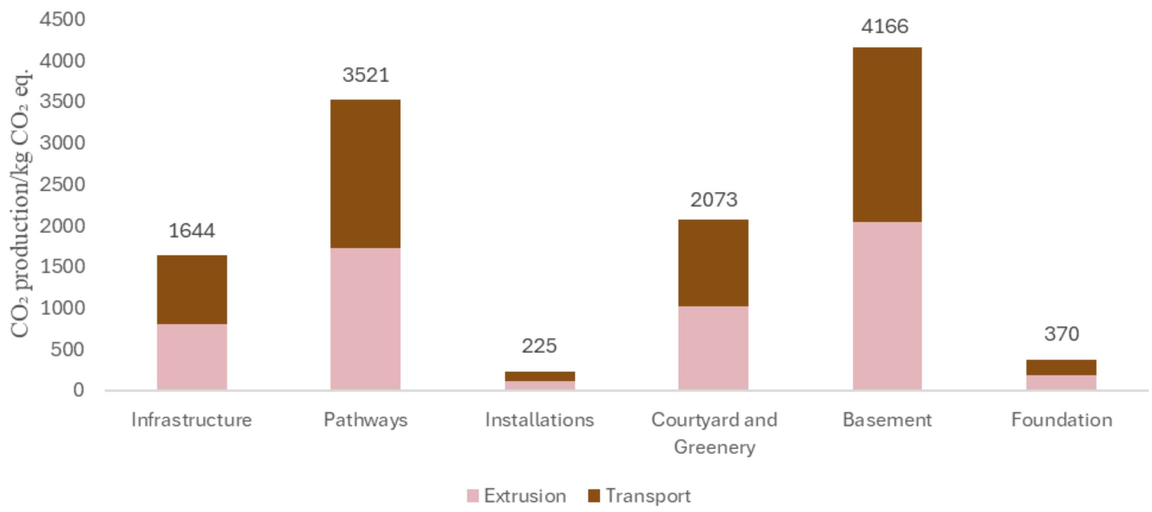

Figure 3.12: Emissions of CO_2 related to Earthworks within different categories.

3.4 Building vs Non-building Elements

This chapter contains results of both building and non-building elements calculations. The outcomes are expressed as carbon density, total amounts within the building site but also as values normalised by the BTA.

3.4.1 Results per BTA

The results presented in the Figure 3.13 are normalized by the BTA of the building comparing original and alternative building structures to the impact of non-building elements. B1 and B6 stages are excluded from these outcomes. In this overview, the non-building elements impact stands out as markedly lower. It is 17 times lower that original structure and 10 times than the improved one.

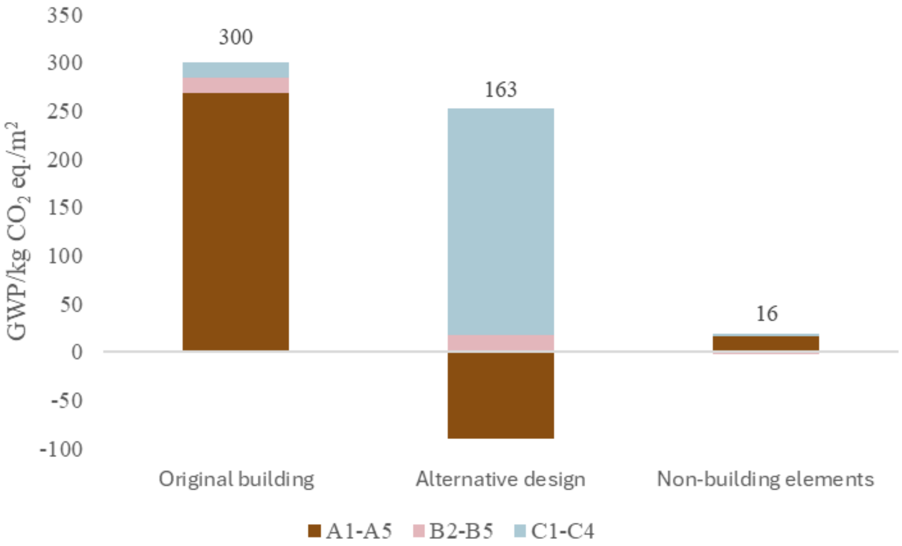

Figure 3.13: GWP per BTA comparison of two building structure scenarios and non-building elements values divided into main LCA stages.

3.4.2 Carbon Density Comparison

The following results compare building's original and alternative GWP values per BTA to the non-building elements carbon impact normalized by its area of footprint. B1 and B6 stages are excluded from these outcomes. The non-building elements result is now equal to 27 kg CO_2 eq./m^2 and is 11 and 6 times lower than original and alternative building structure impact respectively.

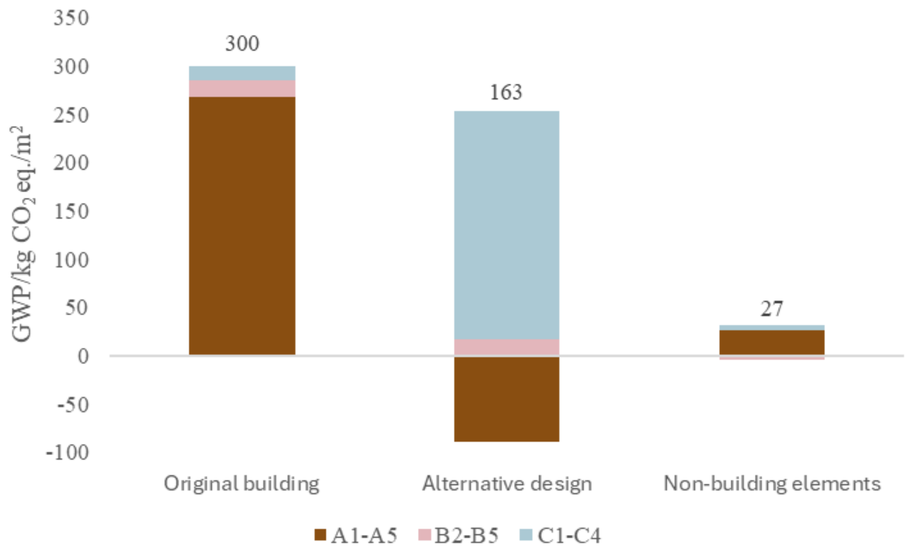

Figure 3.14: Carbon intensity comparison of two building structure scenarios and non-building elements values divided into main LCA stages.

3.4.3 Results within the Building Complex

This chapter presents a complete overview of all the results within the building complex of Oceanhamnen Etapp 2. It includes data across all categories and life cycle stages of the elements, including the B1 and B6 stages and Earthworks. Both building structure scenarios are presented. The functional unit applied throughout the analysis of GWP is expressed in kilograms of CO_2 equivalent [kg CO_2 eq.]. All material quantities used within the site are taken into account and contribute to the overall environmental impact calculations.

Figures 3.15 show the division of the impacts in percentages within the building complex under two building's structural alternatives. As an impact of the structure reduces, by incorporated improvements, the B6 stage, non-building elements and earthworks gain bigger significance.

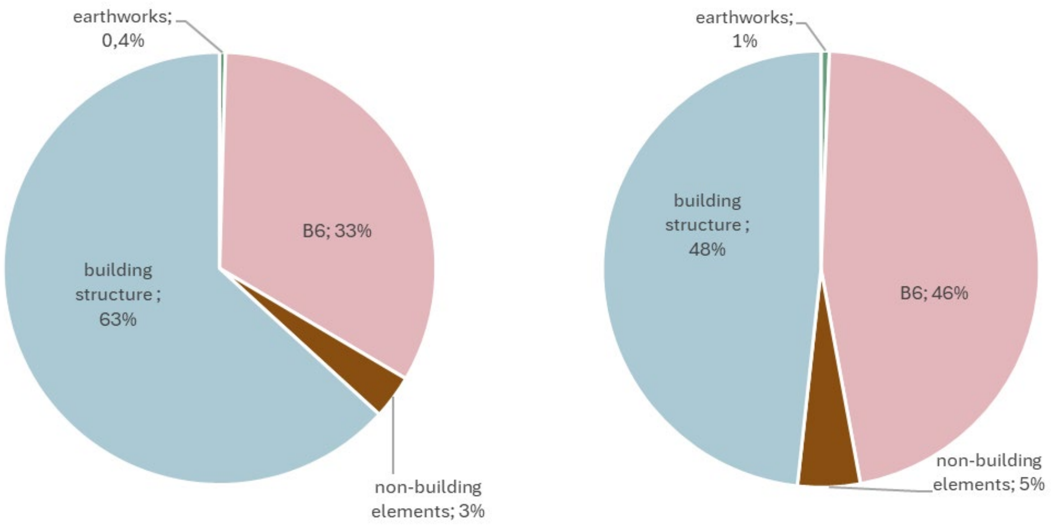

Figure 3.15: Percentage spread out of GWP within the building complex with original building scenario to the left and alternative building scenario to the right

All the components calculated within scope of this study are presented and compared in Figure 3.16. Visible highest impact is related to building structures in both original and alternative design, equal to 1732200 kg CO_2 eq and 941162 kg CO_2 eq respectively. Lowest overall impact in the complex is related to earthworks summing up to almost 12000 kg CO_2 eq. Total impact of non-building elements is equal to 4% of original building total GWP values and 5% of alternative design outcomes.

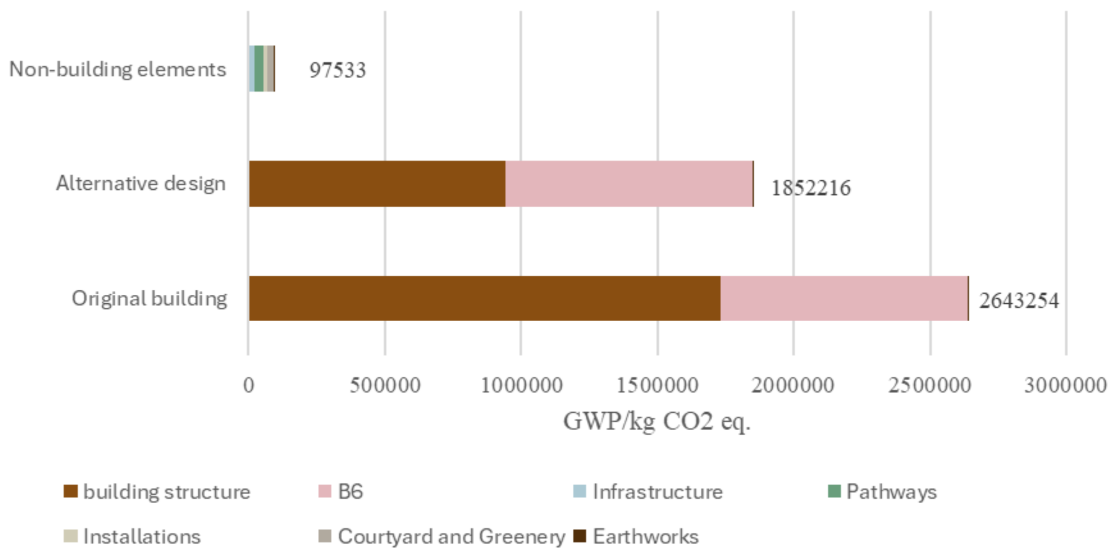

Figure 3.16: Total GWP within the building complex, divided into categories.

Table 3.3 summarizes all the calculated contents and their total GWP values within the context of Oceanhamnen Etapp 2.

Table 3.3: Summary of total GWP values linked to original and alternative building design, non-building elements and earthworks within studied building complex.

Original building design	Alternative building design	Non-building elements	Earthworks
2638718 kg CO_2 eq.	1847680 kg CO_2 eq.	90069 kg CO_2 eq.	11999 kg CO_2 eq.

4.Discussion

This section presents an analysis of the embodied and operational carbon emissions associated with building related components, as well as the global warming potential (GWP) of the surrounding. It identified the main contributing factors across both building and non-building elements and explored the potential strategies for reducing carbon emissions through alternative structures.

4.1 LCA Calculation in Building Scale

Original structure system

The calculated LCA results covered 91% of the carbon emissions in A stage under the same system boundaries as the climate report, so the calculated A stage carbon emissions were similar to the actual conditions. In addition, the energy simulated results showed an 8% deviation compared with the specific energy need in EPC.

To assess how the climate impacts of production stage (A1-A3) and construction stage (A4 and A5) of the original structure system of studied building comparing with the average of Swedish multi-dwelling buildings, an additional benchmark was used to evaluate the A stage climate impact. This benchmark is based on a value of 356 kg CO_2-eq./m^2 BTA, representing the A stage carbon emissions based on Swedish average value of a multi-family building as calculated in the Housing Authority Proposal 2027 (Malmqvist et al., 2023). The same system boundary as the benchmark was utilized, excluding the climate impacts from the basement and PV panels. Under these conditions, the original structure system, with a calculated A stage impact of 235 kg CO_2-eq./m^2, demonstrated a reduction of 121 kg CO_2-eq./m^2, accounting for 34% of total emissions relative to the benchmark.

This marked reduction was due to the selection of materials with low-carbon emissions properties during the construction process, in particular the use of environmentally friendly concrete such as Sweexp ECO-Concrete, Balkong ECO 30, Skalvägg ECO30, etc. Despite this, the production and construction stage (A stage) associated with the original scenario still contribute the most to the climate impact, accounting for 59% of total carbon emissions (267 kg CO_2-eq./m^2), while operative energy accounts for 35% (158 kg CO_2-eq./m^2). However, the building with original scenario, under the LCA calculation during entire lifetime, still exhibited 453 kg CO_2-eq./m^2 carbon emissions.

Alternative structure system

A recent study showed that the CLT, a relatively new building material, has a negative global warming contribution compared to conventional structure materials such as concrete and steel. As CLT serves as a carbon-storing material, it is considered a preferable alternative to the reinforced concrete system (Andersen et al., 2022). Based on these findings, the alternative structure system was designed using a hybrid timber-concrete structure. In this alternative structure system, the structure of the foundation, basement, ground floor and core were retained in reinforced concrete, as these elements were essential for ensuring structure stability. In contrast, several other building components considered in this study that originally included reinforced concrete were replaced with timber-based materials, such as structures frames and slabs. These two components of building together represent 192 kg CO_2-eq./m^2, amounting to 70% of the total emitted carbon from the production and construction stage (A stage). The alternative hybrid timber-concrete structure system demonstrated a substantial reduction in carbon emission, with decreases of 39 kg CO_2-eq./m^2 representing a 51% in the structure elements and 89 kg CO_2-eq./m^2 corresponding to an 80% reduction in the slabs across the entire lifespan.

This significant reduction was primarily due to the use of timber-based materials, which generally have a much lower carbon footprint than reinforced concrete. When calculating the climate impacts of timber-based materials, it was found that the raw materials supply phase (A1) resulted in a negative climate impact of -115 kg CO_2-eq./m^2 during the production stage, while the waste processing phase (C3) showed a significant positive climate impact of 228 kg CO_2-eq./m^2, based on the original EPDs. This discrepancy arises from the unique characteristics of timber-based materials: they have the ability to store biogenic carbon, thereby delaying the release of biogenic CO_2 into the atmosphere (Churkina et al., 2020; Hoxha et al., 2020). For the waste processing phase, only 100% incineration with energy recovery scenario was considered in module C3, as it is the most typical applied end-of-life scenario under European conditions. In this scenario, biogenic carbon flows and energy stored in material are balanced in accordance with the EN 16485 standard.

Overall, the tested design alterations resulted in total GWP reduction of 137 kg CO_2-eq./m^2 carbon emissions, contributing to 30% of total GWP values reduction compared to the building with original scenario and demonstrating a relevant mitigation effect. Although there remains a gap in reaching climate neutrality, replacing the conventional construction materials with low-carbon alternatives presents a practical and effective strategy.

4.2 LCA of Non-building Elements

Using multiple functional units in GWP calculations is essential for interpreting and comparing environmental performance across different contexts. In this study, three units were used: per building complex [kg CO_2 eq.] for project-specific insights, per gross floor area (BTA) for standardized comparisons, and per footprint area [kg CO_2 eq./m^2] for material-specific assessments. While these choices aligned with the study's goals, other units may be more appropriate depending on the focus. For example, impacts of installation systems could be expressed per unit length [kg CO_2 eq./m], or planting areas per soil volume [kg CO_2 eq./m^3]. This highlights the importance of selecting functional units suited to the analysis context.

Looking at the distribution of the GWP values, see Figure 3.7, for main non-building categories, expected outcome occurs which is for more voluminous elements to account for the biggest total impacts. Second highest value is related to Courtyard and Greenery category still due to big area of coverage. However, when Greenery is derived to a different category, see Figure 3.8, the Courtyard still has a comparable value to the Pathways in spite of the area reduction. This is due to its complex design. In contrary to Pathways category, which has relatively simple structure, Courtyard includes, besides layers of paved walkways, small architecture, planting areas, outdoor furniture and different types of finishings. This can be later observed in Figure 3.9, where values were normalised by the area of footprint. Courtyard GWP still stayed as one of the highest and Pathways values dropped drastically. Although covering only 14% of area, Courtyard contributed 32% of non-building related emissions.

Similar tendency is also presented in a Danish study on one of the Copenhagen neighbourhoods (Sjökvist et al., 2025) where roads presented a lower impact in comparison to plazas where the prefabricated concrete tiles, street furniture and lighting were implemented. That goes to show that not only quantities of materials but also the complexity of the project plays a role in assessing carbon footprint.

The Infrastructure category was further divided into Main road, Cycling way and Pavement. Road has indeed the highest environmental impact due to more complex structure that has a function of carrying heavier traffic. Pavement value turned out to be higher than cycling way. It is mostly because it was designed to be paved with bricks, which require additional laying layer and more complicated production process. This pattern again aligns with observed trend, where structural complexity and material processing intensity significantly influence environmental performance.

Split of total GWP values into main LCA stages reveals a pattern within all the categories. The main contributor to the carbon footprint is A stage – production and constructions stage. It is around 75% of the whole LCA. The previously cited Danish study similarly found that 74% of the site's carbon emissions were attributed to the A stages. (Sjökvist et al., 2025). Installations, although they carry the smallest overall environmental impact among the main categories, show the highest proportion in the A stage - 93% - due to the use of high-impact materials like steel, copper, and PVC in piping. C stage is less impactful ranging in around 13% of the total value. B stage is almost negligible for most of the categories, which was expected as it is rarely considered for this type of materials due to its typically low environmental impact. Notably, a high negative value related to B stage can be observed in Greenery. This category accounts for all the plants planned for the complex. Those plants are responsible for the carbon sequestration and by that they overweigh the impact of planting soils layered to make their growth possible. A negative value appears also within the infrastructure category resulting from the carbon capture potential of one of the materials during the B1 stage. B stage was usually non-existent in EPDs of non-building elements. These materials do not produce operational impacts. Maintenance, repairs or refurbishment are not expected for them. Any kind of repairs, that realistically would have to be made to those structures, are counted in as a replacement at the end of their life. Any other actions undertaken that are related to external factors or weather conditions are not included in the LCA boundaries of the B stage.

In order to stop the factor of quantities from affecting the results and to be able to recognise carbon density of the categories, the results were normalised by area of footprint and by BTA. It allowed to create a possible environmental factor that could be used to assess GWP of other similar structures without intricate calculations. Those values correspond to either to area of coverage of the element or to buildings total area that they surround.

Impact of transportation method

Three transport scenarios were calculated in this study to examine the accuracy of A4 and C2 stage values presented in the EPDs. Transportation emissions assessed based on these data turned out to be around 3 times lower than comparable transport scenario using the same mean of transport but calculated manually. This does not explicitly mean that EPDs underestimate their values. When compared to a scenario that uses mixed means of transport, yet is more realistic, the differences do not exceed 17%, which falls within an acceptable deviation range for LCA-based transport modelling.

The trend changes for the Installations category, where generalized scenario shows around three times higher emissions compared to other two. That can mean that in the case of this study EPDs values were overestimated for the lighter, less voluminous materials and underestimated for the bulky, dense materials.

Impact of Earthworks

The environmental impact of earthworks depends on the volume of soil to be extracted. The amount of soil moved directly affects the energy and resources used. Emissions accounting for both the soil extrusion process and its transportation are similar in scale. The emissions related to excavation vary depending on the efficiency of the machinery and the type of soil being extracted. Earthworks are expected to have a minimal impact in this study, as the environmental effects are relatively low.

4.3 Building vs Non-building Elements

To accurately assess the significance of non-building elements GWP, it was directly compared to the carbon footprint of the structures of the building. The outcomes were presented as carbon density, total emissions across the site and values adjusted relative to the gross building area (BTA). Both of buildings structure scenarios – original and improved- were introduced into the comparisons.

As system boundaries of building and surrounding calculations have some differences, it was made sure to compare the values that include the same LCA stages. Despite B1 stage occurring in some of the non-building elements it was subtracted from the outcomes because it was not included in the buildings results. The same way to ensure fairer overview of the results, the B6 stage was excluded from building values due to lack of operational stages in scope of LCA of the surrounding.

Results normalized by the BTA show that impact of non-building elements is equal to 5% of GWP value of original building design and 9% of the improved one. Yet, if the goal is to compare carbon densities of the structures, it is adequate to normalize the results by the area of footprint of each of the structure. This is why in Figure 3.13 building related values stayed the same as they remained adjusted to the BTA. The results of surrounding structures were normalised by its footprint resulting in higher carbon density. Therefore, when comparing carbon densities of these components the surrounding accounted for 9% of the original building LCA and 16% of the improved one.

Looking at the total values of carbon impacts within the building complex, building related emissions account for 96% with an original building structure and 94% with an alternative structure. The percentage distribution throughout the site alters a little when changing the building construction because as its impact reduces, the other impacts become more relevant. The relevance of the building related emissions in the Copenhagen example (Sjökvist et al., 2025) to other elements of the neighbourhood is calculated to be around 80%. It remains a comparable value, especially considering that the referenced study involved a more complex environment with bridges and included heavily impactful element such as underground parking in the non-building-related emissions.

The findings of this study highlight the value of incorporating an extended LCA approach that includes non-building elements in the assessment of building complexes. While their contribution to total carbon impact is relatively small, their carbon density and material complexity reveal important insights for sustainable design. Planning processes should balance aesthetic goals with ecological responsibility. Future research could focus on standardizing functional units and enhancing the precision of EPD data to improve the reliability of such assessments.

5. Conclusions

This thesis examined the life cycle global warming potential (GWP) of an area comprising a newly constructed building and its nearby surroundings in Oceanhamen, Helsingborg, Sweden. The research aimed to quantify the global warming potential of both the building and its adjacent surroundings, while also exploring the method for calculating the LCA of elements that are less commonly assessed. By comparing the climate impacts of the building with its surrounding structures, the importance of each element was found to estimate the relative impact of the surroundings. Furthermore, this study seeks to inform climate-neutral design strategies by evaluating building solutions, with the aim of guiding future research and promoting the development of low-carbon building practices.

Although current building regulation in Sweden only evaluates the A stage of LCA, this study extended the LCA system boundaries and evaluate the building's climate impact across its entire lifetime, based on the available data. The system boundaries in this study were extending two key aspects:

1. Life cycle modules: More life cycle stages were included in the LCA calculations compared to current building regulation, which typically consider only the A stage.

2. Scope: Unlike current building regulations that only focused on the building related components above ground, this study also incorporated below-ground components, solar system as well as non-building elements. These non-building elements included infrastructure, pathways, installations, courtyard and greenery.

According to the calculation result of building related components, carbon emissions of the above ground original building during A stage amounted to 234 kg CO_2-eq./m^2. A considerable reduction in carbon emissions compared with the baseline value of 356 kg CO_2-eq./m^2, which is the average carbon emissions of Swedish multi-dwelling buildings, was due to apply a large number of low-carbon emission materials. Both values were calculated using the same system boundaries as those defined in the Housing Authority Proposal 2027 (Malmqvist et al., 2023).

In addition, when applied the extended components boundaries, the A stage accounted for 59% of the total carbon emissions, amounting to 267 kg CO_2-eq./m^2. Within this stage, the product stage (A1-A3) with conventional construction plays a crucial role in carbon emissions accounting for 45% of total carbon emissions, with 200 kg CO_2-eq./m^2. This value exceeded the impact of operational energy (B6), with 158 kg CO_2-eq./m^2, 35% of the total. Meanwhile, the carbon emissions of modules B2-B5 accounted for 17 kg CO_2-eq./m^2, and the emissions from the end-of -life phase (C stage) contributed an additional 14 kg CO_2-eq./m^2. This finding in emissions profile highlights a critical result: the embodied carbon alone has become the largest source of emissions, emphasizing the necessity to priorities low carbon and carbon-storing material strategies alongside energy efficiency in building design. Reducing emissions in A stage is therefore not only essential but also represent the most impactful opportunity for achieving climate neutrality in new buildings.

Consequently, the hybrid timber-concrete structure system was also evaluated as an alternative to decrease the climate impact of building materials. Due to the biogenic carbon storage properties of timber-based materials, the emissions associated with modules A1–A3 were negative. To enable a fair comparison with the original structural system, climate impacts were assessed across the building's full life cycle. The results showed that the alternative structural system produced 30% (137 kg CO_2-eq./m^2) lower emissions than the original over the entire life span of the building.

The significance of GWP of the surrounding in relation to the building itself is not highly influential. The impact of non-building elements can be roughly assumed to be around 4% of the carbon footprint of the whole building complex. The assessment of the most impactful component of non-building elements is not explicit as the conclusion is highly relevant to the analysed context. Based on conducted calculations and examination of the results, it can be deduced that the highest carbon footprint values are caused by complex designs requiring prefabricated materials. That also aligns with the fact that A-stage of LCA was the most impactful one. Within the studied context, Pathways attributes to the highest GWP, however it is only due to large amounts of materials accounting for this category. Truly, carbon dense component turns out to be the Courtyard, with the value of 58,39 kg CO_2 eq./m^2 taking up 32% of total LCA of non-building elements. The Earthworks play the smallest role in the GWP of the building site and can be estimated to be 1% of it.

Although the overall impact of non-building elements was relatively minor, the assessment revealed a broader trend: increased design complexity tends to raise carbon emissions. This pattern extends beyond non-building components to other parts of the project as well. It highlights a key trade-off for designers - between aesthetic or functional complexity and environmental performance - and underscores the value of thoughtful design choices in minimizing carbon footprint.

When aiming to reduce environmental impact, it is most effective to target the elements with the highest carbon footprint. While improving the energy performance of buildings is already a widespread and successful focus, this study highlights the significant potential in addressing embodied carbon stored in construction materials. One notable example is the choice of structural system - shifting from conventional materials to a hybrid timber-concrete structure can reduce carbon impact by around 30% for this case-study. This demonstrates a valuable opportunity to lower a building's overall carbon footprint from the early design stages.

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Appendix A

The table A below provides the B stage of the BM database and the basis of settlement. Compared to the EPDs of materials, it takes into account more complex usage scenarios.

Table A: The time intervals for calculation of modules B2 and B4, - means that the material is not relevant within the 50-year calculation period

Roof	**Measure for B2**	**Interval for B2 [year]**	**Interval for B4 [year]**
Bitumen	Asphalt coating (minor areas)	15	30
Exterior wall			
Slate panel	Repainting	15	n/a
Window			
Wood-aluminium	Repainting	15	40

Appendix B

Non-building element						
MAIN ROAD	**Source of data**	**Area of coverage[m2]**	**Volume [m3]**	**Mass [t]**	**GWP [kg CO2 eq.]**	**EPD number**
Friction material	Bill of materials of Etapp 1 + architecrural cross-sections	275	66	156,552	1252,16	EPD-IES-0008178
Reinforcement		275	132	495	6926,57	NEPD-9595-9249
Bearing layer		275	22	44	615,7	NEPD-9595-9249
Asphalt		275	13,75	31,63	1061,53	NEPD-5731-5030-EN
CYCLING WAY						
Friction material		150	36	85,39	683	EPD-IES-0008178
Reinforcement		150	72	270	3784,28	NEPD-9595-9249
Bearing layer		150	15	30	420,48	NEPD-9595-9249
Asphalt		150	7,5	17,25	579,01	NEPD-5731-5030-EN
PAVEMENT						
Friction material		200	48	113,86	910,66	EPD-IES-0008178
Reinforcement		200	96	172,8	2440,79	NEPD-9595-9249
Bearing layer		200	20	40	565	NEPD-9595-9249
Bedding layer		200	80	140	1724,77	MD-24063-EN
Bricks		200	12	28,8	532,89	S-P-13340
PATHWAYS						
Geotextile	Architectural plans + cross-sections	1785	-	0,43	2126	S-P 10187
Reinforcement		1785	856,8	1542,24	21820,28	NEPD-9595-9249
Bearing layer		1562	187,44	393,62	5569,16	NEPD-9595-9249
Cast in place concrete		1397	41,91	100,58	1346,57	S-P-06392
Cobbled stone		388	4,95	13,37	203,19	S-P-06392
INSTALLATIONS	**Source of data**	**Length [m]**	**Mass [kg]**			
Water pipes	Technical installations plans + cross-sections	96	2225,48		4592,73	S-P-05494
Gray water pipes		160	84,41		195,29	NEPD-8986-8662
Daywater pipes		7	5,88		13,6	NEPD-8986-8662
Black water pipes		121	38,08		88,11	NEPD-8986-8662
Food waste line		120	50,19		116,12	NEPD-8986-8662
District heating and coolin		170	1215,68		8634,5	HUB-1145
Gas pipes		58	131,7		320,61	HUB-0963
Cable tunnels		223	146,96		340,02	NEPD-8986-8662
Optical cables		57	7,63		19,14	S-P-05723
COURTYARD	**Source of data**	**Area of coverage[m2]**	**Volume [m3]**	**Mass [t]**		
Reinforcement	Architectural plans	496	238	428,54	6006,88	NEPD-9595-9249
Bearing layer		496	20	45,63	639,62	NEPD-9595-9249
Concrete panels		295	21	49,48	853,93	S-P-13340
Stone flour wear layer		21	0,8	1,68	34,4	S-P-08343
Formable playsand		6	2	3,3	42,75	S-P-12715
Land brick		175	14	14	4123,32	EPD-ZWM-20210148-ICG1-EN
Skeletal soil layer		135	41	70,88	853,81	MD-24063-EN
Leveling layer		135	27	40,5	573,07	MD-24063-EN
Planting soil		118	47	62,54	1547,98	MD-24179-EN
Grasstorv		17	3	3,38	173,53	MD-24179-EN
Liming		118	-	0,003	0,027	S-P-12770
Fertilizer		118	-	0,003	0,0004	SP-0955
		Length [m]	**Mass [t]**			
Steel edge support		138	3,25		53,01	EPD-AST-20240033-IBI1-EN
OUTDOOR FURNITUR	**Source of data**	**Amount of pieces**		**GWP [kg CO2 eq.]**		
Bench	Architectural plans	4		1828	0d3e9eb1-e255-4200-93c6-96bb6d67496a	
Chair		15		5295	ce14813f-4aed-4590-a91f-d512e49a2181	
Round table		5		2000	c9fb8695-225b-4727-9650-ad7e73948227	
Rectangular table		3		1602	c9fb8695-225b-4727-9650-ad7e73948227	
Bike rack		24		3336	248ca604-67da-497a-8bd8-eac8d3746f28	
GREENERY	**Source of data**	**Area of coverage[m2]**	**Volume [m3]**	**Mass [t]**		
Skeletal soil layer	Architectural plans + cross-sections	370	111	194,25	2340,08	MD-24063-EN
Leveling layer		370	74	111	1570,62	MD-24063-EN
Planting soil		370	148	196,1	4853,84	MD-24179-EN
Liming		370	-	0,011	0,09	S-P-12770
Fertilizer		370	-	0,011	0,001	SP-0955
		Length [m]	**Mass [t]**			
Steel edge support		146	3,43		56,09	EPD-AST-20240033-IBI1-EN
PLANTS	**Source of data**	**Amount of pieces**				
Trees	Planting and equipment plan	11			-10780	-
Shrubs		149			-3687,75	-
Small plants		869			-129,05	-

Appendix C

Foundation

The foundation information was obtained from a basement construction drawing that outlined the basic structure layout and was the only one drawing providing details on the reinforcement distribution within the shear walls. Based on other technical drawings, the building foundation consists of tree types: independent foundations, bar foundations and pile cap foundations. However, due to the unclear placement of the pile cap foundations, only the bar foundation (700mm×500mm) and the idependent foundation (1000mm×1000mm×400mm) were utilized in strucutre system.

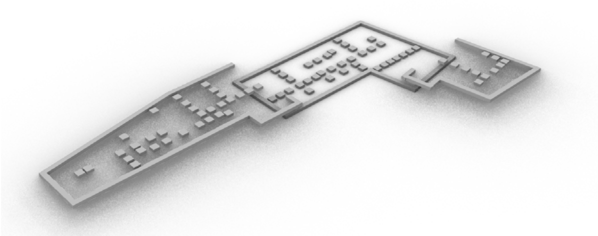

Figure C.1:3D model of bar foundations and independent foundations

Basement

The previously mentioned basement construction drawing was used as a reference to assume the shear walls distribution in the upper floors. To ensure structural stability, concrete of grade C45/55 was used for casting the interior walls, while the same concrete grade with added waterproof properties was applied for the exterior walls.

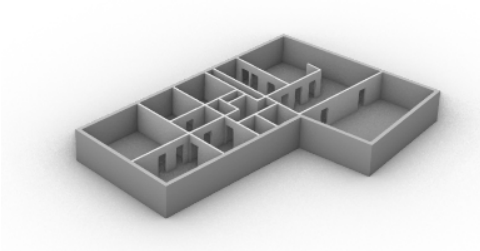

Figure C.2:3D model of basement including interior shear walls

Exterior wall structure

The exterior wall construction can be divided into two parts; one section features double-layered walls connecting the slabs directly to the foundations mainly appeared at the ground floor's slate panel cladding and the rest was served to strengthen the overhanging structure. While the remaining sections supported by beam-column system, the VKR pillars were embedded in the insulation layers with concrete reinforcement.

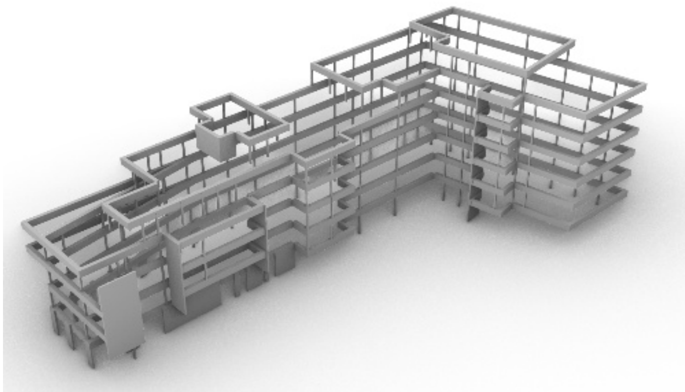

Figure C.3: 3D model of exterior load-bearing structure consisted of double-layered walls and beam-column system

Shear wall

A 200 mm shell wall, consisting of two concrete slabs connected by cast-in-place steel reinforcement bars, was utilized as the interior load-bearing structure extending from the basement to the top floor.

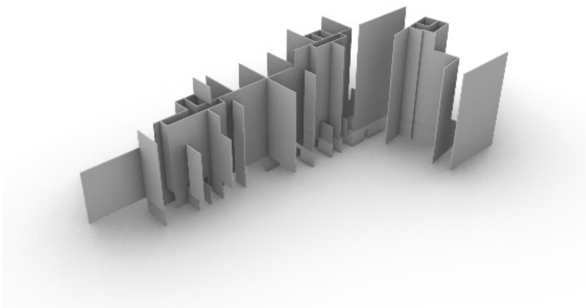

Figure C.4: 3D model of interior shear walls

Slabs

The above-ground slabs were categorized into four types: roof, interior floor, overhang, and ground floor. Except for the ground floor, all slabs generally consisted of a 50 mm Plattbärlag ECO30 layer and 220 mm of concrete. In contrast, the ground floor slab was composed of 200 mm of concrete

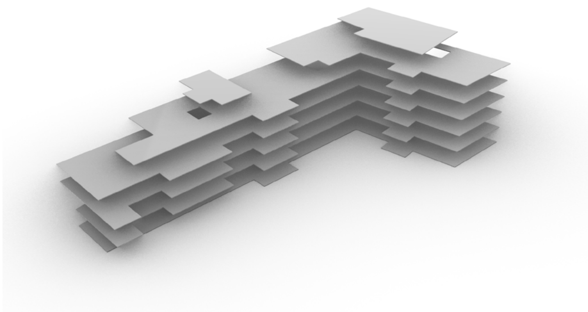

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Figure C.5: 3D model of slabs, including roof, interior floor, overhang, ground floor

Appendix D

Reinforcement ratio

The equation (1) for minimum reinforcement areas was found in EN 1992-1-1(*En.1992.1.1.2004.Pdf*, n.d.).:

$$A_{s,min} = 0.26\frac{f_{ctm}}{f_{yk}}b_t d \qquad (1)$$

but not less than 0.0013

Where:

$A_{s,min}$: Minimum cross-sectional area of reinforcement

f_{ctm}: Mean value of axial tensile strength of concrete, determined with respect to the relevant strength class of concrete

f_{yk}: Characteristic yield strength of reinforcement

b_t: Mean width of the tension zone

d: Effective depth of a cross-section.

For this work, the assumption of concrete grade C30/37 is used. The related information is listed in Table D.

Table D: Characteristics of materials from EKS 11(*Boverkets konstruktionsregler EKS 11*, n.d.)

Description		**Unit**
f_{ctm}	2.9	MPa
f_{yk}	500	MPa
b_t	1000	mm

$$A_{s,min} = 0.26 \times \frac{2.9}{500} \times 1000 \times d = 1.508 \times d$$

$$\rho_{min} = \frac{A_{s,min}}{b_t d} = \frac{1.508 \times d}{1000 \times d} \approx 0.15\%$$

The results show that the minimum reinforcement ratio of C30/37 concrete is 0.15%.

Appendix E

LCA Material Calculation of Building Related Components Tables

Appendix table. E.1: LCA calculation for roof

ROOF	Source of data	Area of coverage [m2]	Volume [m3]	Mass [kg]	GWP [kg CO_2 eq.]	A stage Database	B2-B5 Database	EPD number
VegTechSedumtak	HB model	1139		35549	16282	EPD	EPD	S-P-06070
Takpapp,Sopralene MF5500. UE				6517	28483	Boverket 2023	B&M	EPD-IES-0013722 [S-P-13722]
ROCKWOOL Takboard				3988	4325	EPD	EPD	NEPD-3414-2027-EN
ISOVER Plastfolie 0,20 dubbelvikt				205	2863	Boverket 2023	B&M	NEPD-7425-6813-EN
Cellplast S100				7178	10818	EPD	EPD	MD-24160-EN

Appendix table. E.2: LCA calculation for exterior wall

EXTERIOR WALL	Source of data	Area of coverage [m2]	Volume [m3]	Mass [kg]	GWP [kg CO_2 eq.]	A stage Database	B2-B5 Database	EPD number
Yellow bricks	HB model	1846		199353	38206	EPD	EPD	MD-21062-EN_rev1
Fasadsystem inklusive stålribbor		598		12558	122338	Boverket 2023	B&M	MD-20045-EN_rev4
Isover Skalmursskiva 32		2444		4135	4660	EPD	EPD	NEPD-2079-940-EN
Knauf Danogips Weatherboard 9 GM-H2 1200				13152	19379	Boverket 2023	EPD	S-P-02001
ISOVER Stålregelskiva 35 c450				5648	7019	Boverket 2023	EPD	NEPD-2077-937-EN
ISOVER Piano® Ljudskiva Stål c450 70				1163	1749	EPD	EPD	NEPD-2502-1244-EN

Appendix table. E.3: LCA calculation for exterior floor

EXTERIOR FLOOR	Source of data	Area of coverage [m2]	Volume [m3]	Mass [kg]	GWP [kg CO_2 eq.]	A stage Database	B2-B5 Database	EPD number
EPS 80 insulation	HB model	591		2602	17661	EPD	EPD	S-P-02035
gravel stone				183648	3977	EPD	EPD	-
Votec Fiberduk				3	20	EPD	EPD	HUB-2401

Appendix table. E.4: LCA calculation for overhang

OVERHANG	Source of data	Area of coverage [m2]	Volume [m3]	Mass [kg]	GWP [kg CO_2 eq.]	A stage Database	B2-B5 Database	EPD number
ISOVER Stålregelskiva 35 c450	HB model	80		434	539	Boverket 2023	EPD	NEPD-2077-937-EN
Stålplåt. UE				564	7839	Boverket 2023	EPD	S-P-09023
Aluminium. Plåtslagning tak + fasad. UE				2387	76219	Boverket 2023	EPD	EPD-AUR-20160218-CBA1-EN

Appendix table. E.5: LCA calculation for window

WINDOW	Source of data	Area of coverage [m2]	Volume [m3]	Mass [kg]	GWP [kg CO_2 eq.]	A stage Database	B2-B5 Database	EPD number
Fönster, trä/aluminium. Elit	HB model	955		34921	379927	Boverket 2023	EPD	2021/8/27

Appendix table. E.6: LCA calculation for PV

PV	Source of data	Area of coverage [m2]	Volume [m3]	Mass [kg]	GWP [kg CO_2 eq.]	A stage Database	B2-B5 Database	EPD number
M10 Solar Photovoltaic Panels	Construction drawings	98		2536	38418	EPD	EPD	S-P-06949

Appendix table. E.7: LCA calculation for foundation

FOUNDATION	Source of data	Area of coverage [m2]	Volume [m3]	Mass [kg]	GWP [kg CO_2 eq.]	A stage Database	B2-B5 Database	EPD number
ECO Sweexp40 C45/55	HB model		112	258635	39129	Boverket 2023	EPD	EPD-IZB-20230423-IBA1-DE
Armeringsnät Tibnor			1.68	1333	917	EPD	EPD	S-P-04450

Appendix table. E.8: LCA calculation for basement

BASEMENT		Source of data	Area of coverage [m2]	Volume [m3]	Mass [kg]	GWP [kg CO_2 eq.]	A stage Database	B2-B5 Database	EPD number
EXTERIOR WALL	ECO Sweexp40 C45/55	HB model	396		364373	55126	Boverket 2023	EPD	EPD-IZB-20230423-IBA1-DE
	Armeringsnät Tibnor				2253	1381	EPD	EPD	S-P-04450
	EPS 80 insulation1				673	4570	EPD	EPD	S-P-02035
	gravel stone				142581	3088	EPD	EPD	S-P-06949
INTERIOR WALL	ECO Sweexp40 C45/55	Construction drawings	318		146262	22128	Boverket 2023	EPD	EPD-IZB-20230423-IBA1-DE
	Armering				754	548	EPD	EPD	HUB-2401
BASEMENT FLOOR	Votec Fiberduk	HB model	275		2	11	EPD	EPD	S-P 10187
	Isodrän Board				900	7175	EPD	EPD	S-P-13068
	weber Undervattensbetong				252934	98518	EPD	EPD	EPD-IES-0017999
	Armeringsnät Tibnor-1				2606	1597	EPD	EPD	S-P-04450

Appendix table. E.9: LCA calculation for structure (original scenario)

STRUCUTRE [ORIGINAL SCENARIO]		Source of data	Area of coverage [m2]	Volume [m3]	Mass [kg]	GWP [kg CO_2 eq.]	A stage Database	B2-B5 Database	EPD number
EXTERIOR STRUCTURE	Double-layered walls	Construction drawings	223		53416	11477	Boverket 2023	EPD	ITB No. 134/2020
	ECO Sweexp40 C45/55				87729	13821	Boverket 2023	EPD	EPD-IZB-20230423-IBA1-DE
	Armering				4520	3286	EPD	EPD	HUB-2401
	ECO3 SWEEXP55 C30/37				501150	43119	EPD	EPD	NEPD-2637-1350-SE
	Armering				25820	18774	EPD	EPD	HUB-2401
INTERIOR STRUCTURE	Skalvägg ECO30	HB model	2966		1423600	237319	EPD	EPD	S-P-01653
	Armering				7029	5111	EPD	EPD	HUB-2401
	ECO Sweexp50 C35/45				507700	69956	Boverket 2023	EPD	EPD-IZB-20230422-IBA1-DE
	Armering				26158	19019	EPD	EPD	HUB-2401

Appendix table. E.10: LCA calculation for balcony (original scenario)

BALCONY [ORIGINAL SCENARIO]	Source of data	Area of coverage [m2]	Volume [m3]	Mass [kg]	GWP [kg CO_2 eq.]	A stage Database	B2-B5 Database	EPD number
Balkonger EC0 30, Ucklum	Construction drawings	208		105102	42566	EPD	EPD	S-P-05003

Appendix table. E.11: LCA calculation for slabs (original scenario)

SLABS [ORIGINAL SCENARIO]		Source of data	Area of coverage [m2]	Volume [m3]	Mass [kg]	GWP [kg CO_2 eq.]	A stage Database	B2-B5 Database	EPD number
ROOF	ECO SWEEXP45 C40/50	HB model	1139		576540	83714	Boverket 2023	B&M	S-P-0-6974
	Armering				3366	2448	EPD	EPD	HUB-2401
	Plattbärlag ECO30				142426	26164	EPD	EPD	S-P-01654
INTERIOR FLOOR	ECO SWEEXP45 C40/50		4777		2417300	350995	Boverket 2023	EPD	S-P-0-6974
	Armering				14115	10263	EPD	EPD	HUB-2401
	Plattbärlag ECO30				597165	109699	EPD	EPD	S-P-01654
EXTERIOR FLOOR	ECO Sweexp40 C45/55		591		469324	71004	Boverket 2023	EPD	EPD-IZB-20230423-IBA1-DE
	Armeringsnät Tibnor				2902	1778	EPD	EPD	S-P-04450
OVERHANG	ECO SWEEXP55 C30/37		80		40673	3500	EPD	EPD	NEPD-2637-1350-SE
	Armering				210	152	EPD	EPD	HUB-2401
	Plattbärlag ECO30				10048	1846	EPD	EPD	S-P-01654

Appendix table. E.12: LCA calculation for structure (alternative scenario)

STRUCUTRE [ALTERNATIVBE SCENARIO]		Source of data	Area of coverage [m2]	Volume [m3]	Mass [kg]	GWP [kg CO_2 eq.]	A stage Database	B2-B5 Database	EPD number
EXTERIOR STRUCTURE	Double-layered walls	Construction drawings	223		53416	11477	Boverket 2023	EPD	ITB No. 134/2020
	ECO Sweexp40 C45/55				175457	27642	Boverket 2023	EPD	EPD-IZB-20230423-IBA1-DE
	Armering				9040	6573	EPD	EPD	HUB-2401
	Glue-laminated Posts and Beams				103297	7725	EPD	EPD	EPD-IES-0017091
INTERIOR STRUCTURE	Skalvägg ECO30	HB model	2966		806469	134438	EPD	EPD	S-P-01653
	Armering				3982	2895	EPD	EPD	HUB-2401
	Glue-laminated Posts and Beams				103182	7716	EPD	EPD	EPD-IES-0017091
	LVL [Laminated Veneer Lumber]				57821	15826	EPD	EPD	S-P-09942

Appendix table. E.13: LCA calculation for balcony (alternative scenario)

BALCONY [ALTERNATIVBE SCENARIO]	Source of data	Area of coverage [m2]	Volume [m3]	Mass [kg]	GWP [kg CO_2 eq.]	A stage Database	B2-B5 Database	EPD number
CLT Rib Panel	Construction drawings	208		20661	-45205	EPD	EPD	S-P-09950

Appendix table. E.14: LCA calculation for slabs (alternative scenario)

SLABS [ALTERNATIVE SCENARIO]		Source of data	Area of coverage [m2]	Volume [m3]	Mass [kg]	GWP [kg CO_2 eq.]	A stage Database	B2-B5 Database	EPD number
ROOF	CLT Rib Panel	HB model	1139		73697	-161243	EPD	EPD	S-P-09950
INTERIOR FLOOR	ECO SWEEXP45 C4050				192924	26807	Boverket 2023	EPD	S-P-0-6974
	Armering				1127	273	EPD	EPD	HUB-2401
	Plattbärlag ECO30				47659	8755	EPD	EPD	S-P-01654
	CLT Rib Panel				273566	-598541	EPD	EPD	S-P-09950
EXTERIOR FLOOR	ECO Sweexp40 C45/55		591		469324	71004	Boverket 2023	EPD	EPD-IZB-20230423-IBA1-DE
	Armeringsnät Tibnor				2902	1778	EPD	EPD	S-P-04450
OVERHANG	CLT Rib Panel		80		7996	-17494	EPD	EPD	S-P-09950

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