It is All About the Details

A Life Cycle Assessment on a Building Project in Sweden with Focus on the Level of Details in the Inventory Data

Master's thesis in Structural Engineering and Building Technology

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Department of Architecture and Civil Engineering
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2019

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Cover: Graphic illustration of some articles included in a building project.

Printed by Architecture and Civil Engineering
Gothenburg, Sweden 2019

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Abstract

The use of life cycle assessments within the building industry has increased rapidly during the last decade. In Sweden, new regulations regarding life cycle assessment becoming a benchmark for all new production, refurbishment as well as management of existing buildings has been suggested. However, the effects from a life cycle assessment based on comprehensive inventory data has not been thoroughly investigated. Therefore, the aim of the study was to investigate in the implication of such an assessment, both regarding the workload needed as well as effects on the results. To reach the aim, a case study where a life cycle assessment of the product stage of a building project has been conducted. The inventory data is based on articles provided in a highly detailed cost calculation of the project.

When including comprehensive inventory data, several assumptions and calculations regarding size and content of an article are needed to be able to reach the information needed to choose a suitable reference material. In this thesis, these assumptions and calculations are documented in a new tool called Transformation Index. A low Transformation Index is considered beneficial, both regarding the workload needed by the analyst and the accuracy of the results. It was concluded that the transformations require knowledge regarding the building industry in general as well as specific knowledge regarding the project.

Further, the case study indicated that the benefits of including more details varies depending on which impact category that is evaluated. It was also concluded that the workload and results vary significantly when using different environmental certifications and cut-offs based on Transformation Index. To summarise, it is all about the details.

Keywords: building industry, comprehensive inventory data, full LCA, knowledge, Transformation Index, Transformation Step, workload.

Skillnaden ligger i detaljerna
En livscykelanalys på ett byggnadsprojekt i Sverige med fokus på detaljnivån av inventeringsdata
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Sammanfattning

Användningen av livscykelanalyser inom byggbranschen har ökat kraftigt under det senaste decenniet. I Sverige har nya regler gällande införande av livscykelanalys för nyproduktion, renovering samt förvaltning av byggnader föreslagits. Dock har inte effekterna, till följd av genomförandet av en livscykelanalys baserad på omfattande inventeringsdata, undersökts grundligt. Syftet med denna studie var därför att undersöka konsekvenserna av en sådan analys, både vad beträffar den arbetsbelastning som krävs samt effekterna på resultaten. För att möta syftet har en fallstudie genomförts, där produktstadiet av ett byggprojekt har studerats genom en livscykelanalys. Denna livscykelanalys inventeringsdata var baserad på artiklar som tillhandahållits i en detaljerad projektkalkyl.

Vid användande av omfattande inventeringsdata behövs flera antaganden och beräkningar, gällande storlek samt innehåll i en artikel. Detta för att kunna nå den information som behövs för att kunna välja ett lämpligt referensmaterial. I denna avhandling dokumenteras dessa antaganden och beräkningar i ett nytt verktyg som kallas omvandlingsindex. Ett lågt omvandlingsindex anses vara fördelaktigt, både vad beträffar arbetsbelastning samt resultatens tillförlitlighet. Studiens resultat har gett indikationer på att de antaganden och beräkningar som behövs kräver kunskap både om byggbranschen i allmänhet, men även kunskap gällande det specifika projektet som analyserats.

Vidare har fallstudien visat att effekten på resultaten i de olika påverkanskategorierna varierar vid användandet av olika omfattande inventeringsdata. Ytterligare en slutsats som kunnat konstateras är att arbetsbelastningen och resultaten varierar väsentligt beroende på om olika miljöcertifieringar eller cut-offs baserade på omvanlingsindex används. Sammanfattningsvis, skillnaden ligger i detaljerna.

Nyckelord: arbetsbelastning, byggbranschen, fullständig LCA, kunskap, omfattande inventeringsdata, omvandlingsindex, omvandlingssteg.

Acknowledgements

We would like to express our gratitude to our supervisor Sjouke Beemsterboer for all the support and helpful comments throughout the project. Further, a special thank you to the persons involved in the building project, of which we based our case study, for their engagement and work to give us the information we needed. Finally, a thank you to our examiner Holger Wallbaum for the valuable feedback on our work.

Johanna Henriksson & Elina Ulander, Gothenburg, June 2019

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Abbreviations

A_{Temp}	Square meter of heated floor area
BMA	Building Material Assessment
EPD	Environmental Product Declaration
IVL	The Swedish Environmental Research Institute
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
TI	Transformation Index
TS	Transformation Step

1

Introduction

This chapter will introduce the topic of the study. Further, it will present the aim of the study as well as the delimitations and the method.

1.1 Background

The methodology of LCA (Life Cycle Assessment) was first used in the 1960:s [1], but it was not until in the 1980:s that it first occurred within the construction industry [2]. In the early 21:st century it was starting to develop in a more increasing pace [2], and since then it has grown in importance. Though, the question is whether this growth of LCA has been too fast for the users to be able to use it to its full potential?

In Sweden, Boverket [3] has presented a proposal that, earliest by the year 2020, life cycle assessment should be a benchmark for all new production, refurbishment as well as management of existing buildings. By analysing the major parts of a building regarding global warming potential (also referred to as climate change), Boverket [3] aims to bring forward a building process that is better adapted to both the environment and the climate. Though, according to Heinonen, Säynäjoki, Junnonen, *et al.* [4], there is little research within the construction sector regarding other impact categories but climate change. Other governmental forces wants to push the development even further by incorporating all life cycle stages included in the standard EN 15978, as well as include other environmental damage categories and not only global warming [5].

As stated by Baumann and Tillman [6, p.21] *"it takes a lot of effort to do an LCA study"* and that doing such a study can be overwhelming. Though, it provides a holistic perspective of a product system and provides a tool to challenge difficulties regarding which environmental based decisions to make [6]. Life cycles assessments on buildings might be challenging, even more so than assessments of industrialised processes [1], due to the large complexity of a building and to some extent also the uniqueness of each building project [2].

When setting the system boundaries of an LCA, there might be cut-offs of the products life cycle. These cut-offs can be if a part (or several parts) of the life cycle is negligible compared to others, or when the entire lifetime is not to be considered [6]. To be able to use these simplifications of the LCA process, and to still receive accurate results, different methodologies have been developed throughout the years. In a study from 2013, Lewandowska, Noskowiak, Pajchrowski, *et al.* [7] present some of these methods and the difference in results between them and a full LCA. However, by analysing the different assessments included in the theoretical background of this thesis, what is stated being a full LCA is not unequivocal. Moreover, the amount of work needed to perform a full LCA does not appear in either of these studies. Hence, it is of interest to investigate what the implication of a full LCA might be.

According to Hunt, Boguski, Weitz, *et al.* [8] so-called vertical cuts are preferred. Vertical cut-offs result in including all stages but with a lower level of detail [8]. These types of cut-offs are also used in building LCA through different environmental certification systems that are used, such as BREEAM and LEED. Though, a shift in focus of the buildings life cycle stages, partly due to improved energy performance of newly constructed buildings [9], might increase the use of horizontal cut-offs rather than vertical. By doing so there will be an exclusion of phases instead of details [10]. Including a higher level of details raises the question which effects there will be on the results as well as the effect on the amount of workload needed. This thesis will analyse these effects by comparing different types of vertical- and horizontal cut-offs and thereby investigate if there is a new way to use building LCA.

1.2 Aim

The aim of the study is to investigate in the concept *Full LCA* with focus on using comprehensive bill of resources as inventory data. The study will analyse how a full LCA is defined, what effect it has on workload needed as well as the effects it has on the results. Furthermore, the study aims to understand what is required to be able to perform an LCA based on a comprehensive cost calculation, both in terms of knowledge, resources and information needed.

1.3 Research Questions

To meet the aim of the study the following research question will be answered:

- *What are the implications of a full LCA with focus on using comprehensive bill of resources as inventory data?*

In addition to the main research question stated above, the following sub-questions regarding the definition of a full LCA and how to conduct this type of analysis as well as the outcomes from it, will be considered in the study:

- *What can be defined as a full LCA?*
- *What are the effects on the workload for the person performing a full LCA?*
- *What are the effects to the result of a full LCA based on detailed inventory data?*
- *Given the implication of performing a full LCA, what simplifications can be useful for future LCA methodologies?*

1.4 Delimitations

The study is delimited to the building industry with focus on residential buildings. European standards and Swedish regulations will be used as guidelines for how to conduct an LCA. Moreover, the study is further delimited to the product stage of the building project's life cycle. This since the highest increase of workload when performing a full LCA is assumed to be in the life cycle inventory.

1.5 Method

To fulfil the aim of the study, a literature review regarding the current use of LCA in the building industry was carried out. The literature review focused on how LCA is implemented in existing certifications and how it, by upcoming laws and regulations, will develop during the upcoming years. It also focused on additional values that LCA can contribute with, as well as its limitations. Further, the study also investigated in the use of performing a full LCA within the building industry and how other full life cycle assessments have been conducted. Also provided by the literature study, was information regarding the phases of LCA and how the life cycle of a building can be divided into several stages.

To further reach the aim, a case study on multi story residential buildings within a building project located in Gothenburg was carried out. This case study was performed in the form of an accounting LCA based on a cost calculation provided by the constructor of the project. This cost calculation is in turn based on construction documents and includes the type and amount of materials that will be used to construct the buildings. The case study evaluated the buildings' effect on climate change during a part of their life cycle. Focus was on the building materials used, as well as the production of these materials. The study showed which parameters of the articles provided in the cost calculation, such as amount, volume and manufactures, that are needed to perform an LCA with comprehensive inventory data. The life cycle assessment was then carried out using Microsoft Excel as well as the LCA software SimaPro. Needed information regarding different building materials, such as product declarations, was mainly be established through the environmental database provided by SundaHus. The method of the case study is explained in detail in Section 3.

A new tool, Transformation Index, was developed after a discussion in a seminar group with other students and other professionals in the field of LCA. The seminar included a discussion about the way of processing this type of comprehensive inventory data. Further discussed was to use some type of index to put emphasis on the conducted work needed to transform the information provided in the cost calculation. The tool was further developed during the process of the project (further described in Section 3.2.4).

2

Theory

This chapter will present general information on how to conduct a life cycle assessment and the stages of a building's life cycle. Further, it will present previous research regarding how LCA is used in the building industry today.

2.1 Four Phases of LCA

An LCA is build up by four phases; *goal and scope*, *inventory analysis*, *life cycle impact assessment* and *interpretation*. These four phases will be presented in this section and they interacts as shown in Figure 2.1 [11].

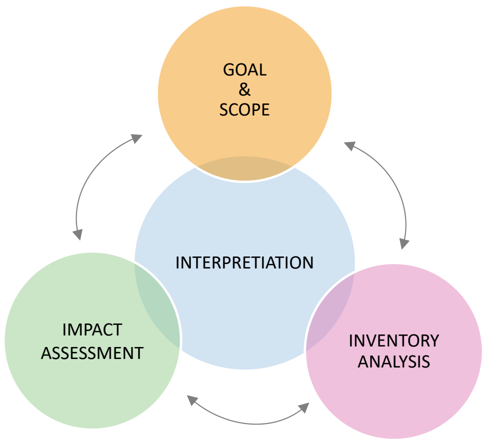

Figure 2.1: *The four phases of an LCA and how they interact with each other.*

2.1.1 Goal and Scope

The first part of an LCA act as a guide for the rest of the work and defines the goal as well as the boundaries of the intended analysis [11]. To achieve a clear goal the context of the assessment should be considered [12] and an iterative process for the goal and scope might be necessary due to changes throughout the analysis [11].

Firstly, the intended audience needs to be considered and defined in the goal [11]. This to be able to know in what way the results should be communicated. The way of communication differs if the assessment, for example, is made for a commercial reason or if a company is choosing between two different components [12]. What to analyse is also considered in the goal, both regarding what product that is being analysed and the reason why it is being analysed [11]. Finally, the purpose of why the assessment is executed should be considered [11].

In the scope, the framework of the assessment is formulated. There are several aspects needed to be discussed and described in this part of the assessment [11]. Foremost, the product system and its functions need to be distinguished [11]. This can be made by an initial flowchart that illustrates the system in general [12]. To be able to implement the functional unit of the product being analysed, the function of the system is needed [13]. This so called functional unit is used as a reference unit and needs to be of a quantitative manner [12]. Moreover, if two or more product system are investigated the functional unit needs to be the same to be able to make a comparison [13].

In an LCA, system boundaries need to be determined [11]. These boundaries are defined to meet the goal of the analysis and explains which different processes that are included in the LCA [11]. One type of boundary is the one describing the geographical restrictions of the process. These geographical boundaries might take into consideration the origin of the raw material and from where the energy used in the production of a product is bought [12]. Another system boundary is the time horizon, which is a boundary that defines which processes of a product system that is included [12].

In many cases, the production of one type of material might also result in one or more types of byproducts. Baumann and Tillman [12] states that the effects on the environment, as well as the inputs and outputs to consider in the LCA, should in that case be divided between this main product and the byproducts. This division, called allocation, can be made in different ways. This could for example either be made through a mass proportion or an economical proportion, which needs to be defined in the scope of the assessment [12].

2.1.2 Inventory Analysis

The inventory analysis phase of the LCA is supposed to quantify and list processes and materials used during the lifetime of the product system [12]. This information will then be used as inputs in the life cycle impact assessment. These inputs could be raw materials used for the product, energy needed for the production or transportation, as well as different types of emissions and material wastes [12]. However, the inventory analysis only includes the in- and outputs that are within the system boundary, stated in the scope. Therefore some in- and outputs of the product might be excluded [11]. The initial flow chart created in the scope is later developed through an iterative process during the inventory analysis [12]. Further, to achieve a transparent result, information considering the data that is collected should be described in the assessment. This description of data should include where and when the data is collected [11].

Different types of inventory data can be used for an LCA. One type of LCI (Life Cycle Inventory) data is generic data that is based on average values for a certain area, e.g. of a national level [14]. The other type of data is the specific data that can be presented in EPDs or another product specific information [14].

2.1.3 Impact Assessment

The third phase of the LCA is an impact assessment, where the quantitative data collected in the inventory analysis is used to evaluate the system through different indicators. This to be able to achieve the aim of the assessment set in the goal and scope [11].

The impact assessment consists of three mandatory stages; impact category definition, classification, and characterisation [11]. When the impact categories are defined, the aim stated in the goal and scope should be considered when deciding which environmental issues, regarding the product system, which is of relevance for the assessment [12]. Further, the different stressors in the result, given in the inventory analysis, should be sorted and classified according to the right impact category. Some stressors might have their place in several impact categories [12]. The last mandatory stage in the impact assessment is the characterisation. In this stage, different stressors within the same impact categories are, through an equivalency factor, calculated into one single environmental impact [12].

The impact assessment also includes different optional steps, one being normalisation. This step is used to be able to simplify the comparison with other values, such as the gross value for a specific region or country [15]. Another step, grouping, is used to achieve an easier overview of the result by grouping the results from the impact assessment into different sets [15]. The result has already been grouped when the impact categories where conducted. However, in this stage other types of sets are used, such as grouping based on what geographical area the where impact occurs (locally or globally) [12]. The last optional stage, according to the standard [11], is weighting. This step is conducted to be able to priorities between different impact categories [15].

2.1.4 Interpretation

The last phase of an LCA consist of three parts according to the standard [11]. Foremost, an interpretation of the results given by the impact assessment as well as an evaluation of the questions related to the goal and scope of the LCA, should be conducted [15]. Further, to evaluate the robustness of the assessment, tests should be conducted [15]. Such tests establish the completeness of the assessment and the appropriateness of the chosen methodology regarding the goal and scope. It also establishes the quality of the data as well as how sensitive the results are for changes of input data or variation of life cycle models [12]. Finally, conclusions drawn from the study should be presented together with the limitations of the study as well as further recommendations [15].

2.2 Life Cycle Stages

The life cycle of a building can be explained with several stages according to the standard [16]. The life cycle consists of four stages and one additional complementary stage, see Table 2.1.

Table 2.1: *The life cycle stages according to SS-EN 15978:2011 [16] of a building's life time and their respective activities.*

Stages	Activities
I - Product stage	A1 - Raw material supply A2 - Transport A3 - Manufacturing
II - Construction process stage	A4 - Transport A5 - Construction-installation process
III - Use stage	B1 - Use B2 - Maintenance B3 - Repair B4 - Replacement B5 - Refurbishment B6 - Operational energy use B7 - Operational water use
IV - End of life stage	C1 - Deconstruction C2 - Transport C3 - Waste processing C4 - Disposal
V - Benefits and loads beyond system boundaries	D - Reuse / Recovery / Recycling potential

The first stage is called *product stage* and comprises production of building materials, including the extraction of raw materials, transportation of these to factories and the entire production process to a finished product [16]. These steps, A1-A3, are considered as cradle to gate for the building material.

The next stage is the *production process*, including activity A4-A5, which corresponds to the construction of the building. Transportation of materials and equipment to the construction site is included, as well as damaged gods during the transportation [16]. Further, work conducted on the construction site is included as also temporary works, waste management, heating or cooling needed due to weather conditions and transportation on site [16].

The third stage, which in time is the most extensive, is the *use stage*. This stage, including activities B1-B7, comprises energy and water use, but also maintenance of the building as well as needed repairs, replacement and refurbishment [16].

Finally, the fourth and last stage of the building's life cycle is the *end of life stage*, including activities C1-C4. This stage comprises deconstruction and demolition of the building as well as transportation, processing and disposal the waste [16].

In addition to these four stages there is a fifth stage called *benefits and loads beyond the system boundaries*, in other words activity D. This stage includes the possibility to reuse, recover or recycle materials used in the building [16].

2.3 Application of LCA in the Building Industry

This section presents to what extent LCA is implemented in the building industry. It describes the appearance of LCA in current certifications and how the environmental work regarding the building industry in Europe will develop in the near future. Further, it also describes how LCA is used in the building industry today, including the additional values of which it contributes, different LCA tools and possible limitations.

2.3.1 LCA in Environmental Certifications

Within different optional environmental certifications such as BREEAM, LEED and Miljöbyggnad there are requirements of including an LCA. In Miljöbyggnad 3.0, (further referred to as Miljöbyggnad) there is a demand on performing an LCA only including the foundation and the structure [17]. Further, the LCA only needs to include the life cycle stages A1-A4, stated in SS-EN 15978 [16], and only include the impact category climate change. Though, according to Boverket [17], the demand on the LCA that should be included in LEED v4 and BREEAM-SE 2017 (further referred to as LEED and BREEAM) is more extensive. Climate impacts other than climate change should be included in both BREEAM and LEED, although climate change should be one of them. Further, BREEAM issues points for the roof, windows, external and internal walls as well as the floors and upper floor slabs [18]. In difference, the foundation should be included in LEED, as well as the building envelope and the structural elements [17]. Another aspect that differs BREEAM and LEED from Miljöbyggnad is the time for performing the LCA. In BREEAM and LEED, LCA should be in the early design process, while it is undefined in Miljöbyggnad [17].

2.3.2 Upcoming Environmental Work in Europe

The climate is changing all over the world and different types of laws and regulations, both in Europe and in Sweden, are being imposed or improved to decrease the environmental footprint. As mentioned in Section 1.1, Boverket [3] has proposed that climate declarations based on life cycle assessment, including the life cycles activities A1-A3 in EN 15978, should be a benchmark for almost all buildings. This climate declaration, according to their proposal in the report 2018:23, would focus on climate change, based on the building's structural components, interior walls and climate screen [3]. Boverket [3] states that the focus on climate change is due to the complexity of performing a climate declaration including other environmental impact categories. The response from Upphandlingsmyndigheten (the Swedish administrative authority of procurement) [5] is that they would like to see even stricter regulations. Instead of only including the activities A1-A3, they would like to see that all activities of the building's life cycle should be included [5]. Further, Upphandlingsmyndigheten [5] would like for not only climate change to be included in the climate declaration, but also other environmental impacts. This since they states that climate change is not the only impact important for a sustainable development [5].

2.3.3 Field of Application of LCA

A frequently mentioned additional value by performing an LCA on a building is increased knowledge. Boverket [19] describes that an LCA contributes with information about what type of impact a building has on the environment and the degree of this impact.

In excess of increased knowledge, life cycle assessments can also contribute with transparency regarding environmental impacts [20]. Further, the interest of the environmental impact of buildings has increased and stakeholders, such as investors and tenants, want more information regarding environmental aspects. Such information is possible with this type of transparency [20].

Further, a possible use of LCA is to implement it in the decision-making. Ströbele and Lützkendorf [21] explains that it can be used when choosing between different products when taking environmental aspects into consideration. The possibility to make these environmental based decisions decreases with time during the project, and hence it is important to implement LCA early in the project [19]. In addition to using LCA to choose between existing products, LCA can also be a tool to develop new and more environmentally friendly products and processes [19].

Another additional value that an LCA can contribute with is to use it for marketing reasons. Carlson and Pålsson [15] explains that the results given from an LCA can be used in marketing of a product to be able to present its environmental benefits.

2.3.4 Full LCA

As mentioned in Section 2.3.1, there is no guidelines or framework in what should be included in a full LCA. The European Committee for Standardisation has through ISO 14040 [22] and ISO 14044 [11], as presented in Section 2.1, provided standardised methodology and framework for performing an LCA. However, the level of details regarding the LCI data is not specified. Further, different studies appear to have different interpretation of what is being regarded as a full LCA. Oregi, Hernandez, Gazulla, *et al.* [23] and Cuéllar-Franca and Azapagic [24] claim performing a full LCA by including all stages of the life cycle, from extraction of raw materials to demolition of the building and recycling of the building materials. Emami, Heinonen, Marteinsson, *et al.* [25] on the other hand claim performing a full LCA by using a higher level of details regarding the LCI data by including more material than the main materials. Though, looking at these studies, a relation between the range of the study and the level of LCI data can be observed. The level of detail of the studies analysing buildings is less than the ones analysing a part or a detail of a building. Further, in a study of two residential buildings, Emami, Heinonen, Marteinsson, *et al.* [25] states performing a detailed LCA, which can be assumed equivalent to a full LCA. The authors of the study state that there is a lack of other studies including the same level of details regarding the LCI data. This study also includes a comparison between fifteen of the different impact categories available in ReCiPe Midpoint method (see Figure 3.3). Another similar study by Vitale and Arena [26], analyses the effect a residential building has on different impact categories along three stages of its life cycle. Both in the study conducted by Emami, Heinonen, Marteinsson, *et al.* [25] and by Vitale and Arena [26], the LCI has been based on a comprehensive bill of quantity (also called Bill of Resources).

2.3.5 LCA Tools

In terms of the inventory process, there is a need of locating information regarding different articles included in the evaluated system. Swedish University of Agricultural Sciences [27] claim that it is important that the data used in an LCA corresponds to the actual article in both time and geographical aspects. One way of gaining information about building materials is through different databases [27]. Some databases are connected to a specific software, such as the Swedish database, *IVL:s Miljödatabas Bygg* conducted by IVL (the Swedish Environmental Research Institute), used in the software *Anavitor*. Other databases can be used in several software products, such as *EcoInvent* and *Impact* [14]. These databases generate generic information. Although, if specific data is preferable, EPD (Environmental Product Declaration) can be used instead [14]. In addition to EPDs, there is a Swedish declaration of products, called BMA (Building Material Assessment), which gives information about the material composition of a product [14]. Boverket [14] explains that the difference between EPD and BMA is that an EPD is controlled by a third part, while a BMA is not. Further, BMAs does not have to include the type or amount of emissions caused by producing a specific product, in difference to an EPD [28]. Moreover, there is a Swedish database called SundaHus that consist of information, such as EPDs and BMAs, regarding building related products [29]. SundaHus [30] state that their database is created to make it easier to do environmentally friendly choices between different products within the building industry. This database is currently consisting of over 40 000 products from over 4 000 brands and more than 9 000 different chemicals compounds [30].

As mentioned above, different software can be used to conduct a life cycle inventory analysis. Two of the most commonly used, according to Emami, Heinonen, Marteinsson, *et al.* [25], are SimaPro and GaBi. One of the differences between them is that SimaPro can be used with several databases, for example EcoInvent, while GaBi is compatible only with its own database [25]. However, Emami, Heinonen, Marteinsson, *et al.* [25] mentions that both SimaPro and GaBi has the possibility to use different types of impact assessment methods. Though, Glaumann, Malmqvist, Peuportier, *et al.* [31] claims that to be able to perform an LCA on a building, using LCA tools such as SimaPro or GaBi, there is a need of experience in these types of software.

IVL Svenska miljöinstitutet [32] has developed a more local tool, *Byggsektorns miljöberäkningsverktyg, BM*, adapted for Swedish buildings, which is based on the database IVL:s Miljödatabas Bygg. Within this tool, commonly used building materials, within the Swedish building industry, are collected. This to enable an average result of a building placed in Sweden [32]. The tool is constructed to meet the new regulations in the environmental certification *Miljöbyggnad 3.0* and hence, only materials comprised in the foundation and the framework of the building is included [32].

2.3.6 Limitations

Even though there are standardised LCA methodologies as well as standardised ways of documentation, different analyses are not necessarily comparable with one another. This since system boundaries can be different between different assessments as well as the type of LCI data being used and which impact categories that are being evaluated. Further, Proctor and Royal Society of Chemistry (Great Britain) [33] describes that the goal and scope will limit the work to the chosen system boundaries, which can lead to an incomplete analysis depending on which limits that has been selected. Though, the fact that several impact categories can be evaluated contributes with a broader picture of the environmental impact of the studied system [33].

As mentioned in Section 2.3.5, there are several databases for building materials. Kylili and Fokaides [34] states that EcoInvent and GaBi are the most complete databases and the ones with the most transparency. Though, there are several other databases and among them several national ones. However, the databases are based on geographical parameters such as manufacturing processes being specific to a certain country [34]. Even if the geographical reference material in the database matches the building material used in a specific building, the same material can be produced in different factories. Different energy mixes as well as the distances for transportation might vary, decreasing the accuracy of the results [35]. Due to the processes being dependent on geographical parameters, there is a need of gathering national data for building materials [34] [36].

The selection of database, as well as if the LCI data should be specific or generic, is of importance regarding the results of the assessment. Lasvaux, Habert, Peuportier, *et al.* [37] has performed a study where results from an LCA based on generic data found in the EcoInvent database were compared with an analysis based on French EPDs. The study showed that the results for the two assessments varied. Though, the magnitude of the differences varied depending on the impact category being evaluated [37]. Some of the impact categories, such as those regarding radioactive waste or photo-chemical ozone formation, shows a large difference depending on if generic data or EPDs was used [37]. Further, Lasvaux, Habert, Peuportier, *et al.* [37] mentions that the differences in results for the impact category global warming potential were indistinct. The selection of software might also have a significant effect on the results. This is shown in the study by Emami, Heinonen, Marteinsson, *et al.* [25], where two buildings are analysed using the same inventory data in the software products GaBi and SimaPro. The study shows that the results differ fifteen percent in average, for the fifteen impact categories tested, depending on the software being used [25].

If the manufacturer of a specific building material is known, using EPD:s could be a way of increasing the accuracy of an LCA including the stages A1-A3. However, even though there are manufactures providing EPDs, there is still a limited source of information regarding LCI data availability [38]. Except for limitations regarding the LCI data, there might be knowledge-based limitations when it comes to selecting the most suitable impact model for the analysis [39]. Further, even if the best suitable model is selected, the interpretation and the understanding of the results can be limited by the performer [38]. Moreover, the lack of knowledge and experience might lead to another vital aspect regarding LCA. An LCA, and a detailed LCA in particular, might demand an excessive amount of resources, as well as being time-consuming [38] [40].

3
Case Study

To be able to achieve the aim of the thesis a case study was conducted, which is presented in this chapter. This intention of this study is to contribute with knowledge on how an LCA based on the cost calculation of the building project, can be conducted. This case study highlights difficulties that might occur during the assessment, as well illustrates in what way an LCA with comprehensive inventory data will effect the workload needed as well as the result.

3.1 Goal and Scope

An accounting LCA, based on a detailed cost calculation, was carried out during the construction phase of a multi storey residential building project in Gothenburg, Sweden, in 2019. The project consists of several buildings with a common garage and basement. The heated floor area of the project is 22 645 m^2 and and is divided between 112 rented apartments, 132 cooperative apartments and an assisted living facility for people with disabilities. The buildings consist of a cast in situ concrete foundation, prefabricated concrete structural elements, glue laminated timber roof beams with sheet coating and internal walls with steel joists. The project is a partnering project between a local building commissioner and one of the major contractors in the Swedish building industry.

Due to confidentiality the project's cost calculation is not allowed to be published, and thereby also information regarding manufactures and amount of the building materials used. This in turn results in the list of inventory data not being published. Therefore, only the results and given examples on included and excluded articles are presented in the case study.

3.1.1 Goal

This assessment aims to show the effects on data quality due to converting the data with the unit given in the cost calculation, to data with a unit suitable for the reference material used in the LCA software. It also aims to show what effects an LCA based on a detailed cost calculation has on needed workload as well as the results. The final aim of the assessment is to evaluate the effect the building materials, used for the buildings, have on different environmental impacts. The environmental focus of the LCA is on climate change, in accordance with the focus of the building industry [9]. The parliament of Sweden has decided that the emission of greenhouse gases in Sweden in total should be zero, by the year of 2045 and the building industry is an important sector in this matter [41]. However, the assessment also investigates in the effects this building project has within other impact categories. This since scientists has discovered that there are other environmental problems than climate change which occur due to the building industry, such as the use of sand in the production of concrete leading to a risk of depletion of raw material [42].

3.1.2 Functional unit

As for the functional unit, the square meter of heated floor area is used, [A_{Temp}]. This unit is used since it is commonly used in similar studies [26] [43], both in Europe and in Sweden. Furthermore, it enables comparison for future assessments performed on other similar buildings. The functional unit does not take any time period into consideration since the study only considers the product stage of the buildings' life cycle.

3.1.3 System Boundaries

This LCA was made only taking the product stage into consideration, which corresponds with activity A1-A3 of the life cycle stages (see Section 2.2 for explanation). These activities include extraction of raw materials and transportation of these to the locations where they are processed and used for manufacturing of building materials. Finally, even though most materials come in packaging, the packaging is not included in this assessment. However, the amount of wastage during the construction phase of the buildings, calculated by the contractor, is included.

Included in the assessment are the residential buildings as well as the common garage and basement. However, piles with additional components connected to the pile work are not included. Further, extended buildings located on the inner yard, such as the fan room and the garbage room, are not included. Moreover, materials needed for kitchen cabinets, wardrobes and other interiors, as well as installations such as ventilation and electricity, are excluded. Finally, the processes regarding transportation and assembly of the components of an article, which have no suitable reference material in EcoInvent, are neglected in this study.

The origin of the articles used for the building project is not considered since the study is based on generic data. The origin of the reference materials is mainly set to Rest of Europe or Switzerland. Other origins are used when suitable.

3.1.4 Impact Assessment Methods

Among the different methods available in SimaPro 8.5.2.0, there are several that can be used for the impact assessment. For this study the method *ReCiPe midpoint H* is used. ReCiPe was selected since it provides a holistic view and according to Joint Research Center [44] it also provides qualitative results for several of the impacts categories calculated. Further, it allows comparison with other similar buildings. There are three possible perspectives for the ReCiPe midpoint method. The perspective Individualist (I) is used with a short-term perspective regarding the impact category climate change [45]. Though, the environmental impacts of a building endures at least its lifetime of 50 years. Therefore, a short-term impact method is unsuitable for a building LCA. Further, according to Goedkoop, Huijbregts, Heijungs, *et al.* [45], the perspective Egalitarian (E) is suitable for climate change with a perspective of 500 years, which is not suitable either. This due to uncertainties a perspective of such a time frame brings. Finally, the last perspective, Hierarchist (H), is in climate change aspects suitable for a time frame of 100 years and is therefore used for this LCA [45].

3.2 Life Cycle Inventory

To be able to perform the assessment the information regarding the building materials provided in the cost calculation, had to be analysed, organised and quantified. In *Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method* [16, p. 30] it is stated that *"...quantification should be organised in a structured way"*. How this is achieved is presented in following sections.

3.2.1 Inventory Data

Before the start of the construction of the buildings, a cost calculation was conducted. This cost calculation consists of the type and the amount of different articles that will be used to construct the buildings. It also consists of information of the needed workload and sometimes also information regarding packaging, transportation costs and the manufacturer of a specific article. In the provided cost calculation, every article has an account number that provides certain information such as whether the article is connected to labour, a group of materials or transportation. Further, every article is also connected to a building element such as the ground slab, internal walls or floor surfaces. The original cost calculation has in this assessment been transformed and sorted so that all articles are placed on separate rows, which made it possible to evaluate each building element separately. This sorted list will further on be referred to as the *Bill of Resources*.

In this case study, the Bill of Resources is used to conduct the inventory analysis. The first step of creating the list of inventory data is by creating separate lists for each building element, further on referred as *Building Element Lists*. In the Bill of Resources, one type of article can appear on several rows. In the Building Element list on the other hand, each type of article is summarised into one row. However, the same article can occur on several Building Element Lists.

Already during the transformation from the Bill of Resources to the Building Element Lists, articles related to account numbers outside of the buildings' life cycle got excluded. Further, building elements that are not included in the system boundaries were also excluded before the conduction of the Building Element Lists. When the Building Element Lists were completed, a new exclusion begun. This time each article is considered separately, and only articles within the system boundaries are kept.

In the Building Element Lists, articles have different kind of units such as length, area, volume, pieces or mass. In the software SimaPro, on the other hand, the reference materials are often presented in mass or volume. Therefore, there was a need to transform the units in the Building Element Lists into the same units as the reference materials before it is added in the software. These transformations were conducted in an additional list, *Transformation Lists*. Further, information regarding the material content of the articles, as well as the ratio between them, is presented in the Transformation List. These lists were also used to analyse the ratio of articles where assumptions were needed to transform the unit in the cost calculation to the unit of the reference material. The next stage in the inventory analysis was to use information collected in the Transformation List, that is type and amount of materials, to find suitable reference materials in the EcoInvent database.

3.2.2 Assumptions and Calculations

As mentioned in Section 3.2.1, assumptions and calculations for the transformation regarding the original cost calculation to the reference material have been necessary, and these are conducted in the Transformation Lists.

The amount of work needed decreases if an article could be transferred and used directly in SimaPro, without any assumptions or calculations other than the type of reference material being made. This is for example the case for the different types of concrete and reinforcement being used in the building project. Suitable reference materials for these articles, having the same unit as the articles in the cost calculation, were found in the EcoInvent database. However, this is not the case for all articles and therefore different types of assumptions are necessary. If there was not a suitable reference material for an article, suitable reference materials of the article's components were used instead, neglecting the production of the article. Further, components having no suitable match in the EcoInvent database have had to be investigated further. This by analysing their sub-components, which often consists of different chemical compounds, and examine whether these have suitable reference materials instead. If there was no suitable match for a sub-component, it was excluded from the assessment.

Further, the manufacturer of an article is sometimes provided in the cost calculation, and sometimes even the name of the article. In those cases, information needed for transforming the unit of the article has been found either on the web page of the manufacture's, the web page of a supplier, or in the database of the platform SundaHus. This results in less need of assumptions regarding the components, or sub-components, of theses articles. However, there was sometimes a need of assumptions regarding the size that is needed to make the transformation to the right unit. Further, even though components of an article were found, as well as the amount of these, the type of the components was sometimes undefined. Instead they were named as e.g. "Material A" and "Material B". This meaning that even though information about the article was found, assumptions regarding the content still had to be made. Another issue regarding information concerning components is that the exact amount of each material rarely is stated in SundaHus. Instead the amount is presented as a definite or an unlimited range, for example "Wood: 10-15 %" or "Manganese: <3 %". In those cases, there were also a need for assumptions regarding the amount of each component.

For several articles there was no known manufacturer or known product name. For these articles there was always a need of assumptions. These assumptions were based on information from products with the same usage as the article with unknown manufacturer or brand. Thereby there is an uncertainty whether the assumed information is the same as for the product that will be used in the buildings.

To receive results as close as possible to the reality, the amount of assumptions has been kept at the lowest level possible. However, the information in the cost calculation is lacking and assumptions have therefore been necessary. A summary of the number of articles where assumptions were needed shows that 20 percent of the articles that are included in the LCA has been chosen without any assumptions. The amount of articles transformed without any assumptions are presented, by each building element, in Table 3.1.

Table 3.1: *The amount of articles which not needed assumptions to be able to be transformed from the original cost calculation to the reference material in the software. The articles are presented for each building element.*

Building element	Amount of articles	Articles without assumptions
Ground construction, complementary	14	29%
Ground construction	24	29%
Ground slab	19	37%
Structural elements, walls	20	20%
Prefabricated elements	1	0%
Structural elements, beams	13	31%
Steel work	13	77%
External roof	21	5%
External roof, complementary	22	0%
Sheet metal	1	0%
Building complementary, steel	7	0%
Structural elements, complementary	19	26%
Windows and doors	51	4%
Building complementary	12	33%
Sub floor	2	0%
Internal walls	21	48%
Ceiling	17	47%
Internal doors and windows	32	3%
Internal stairs	1	0%
Surface layer, floor and stairs	8	0%
Surface layer, walls	6	0%
Surface layer, roof and false ceiling	6	0%
Painting	1	0%
Transportation, elevators	1	0%

3.2.3 Excluded Articles

As mentioned in Section 3.2.1, articles outside of the building's life cycle got excluded. These articles are related to two of the account numbers in the cost calculation, regarding labour on sight and regarding freight. Further, several building elements have been excluded from the study. Some of them since they do not belong to the product stage, for example *Installation work* and *Planning*. Others are excluded because the only information stated was that they were supposed to be performed by a subcontractor and did not specify the type and amount articles being used, such as *Heat and sanitary* and *Electricity*. Finally, building elements regarding interior design, such as kitchen fitments and storage areas, have not included.

Furthermore, articles that do not belong to the given system boundaries, presented in Section 3.1.3, have been excluded. Articles associated to the concrete form, transportation of products and materials for the extended buildings on the inner yard are examples of such articles. Furthermore, piling has been excluded from this study, due to piles not being included in the cost calculation. However, there are articles included in the cost calculation that are in connection with the pile work, and since piles have been excluded so have these articles.

Moreover, articles have been excluded during the progress of the project. One common reason why most of these articles were excluded is that the material of these article could not be specified, or the fact that they were not provided in a countable amount. This is the case for nails that sometimes are presented in a length or an area, and fasteners that sometimes are presented in sets. Regarding the number of nails, the length or the area refers to what nails are used for. The nails could, for example, be used for fasten the splines and the number of nails then depends on the length of the splines and the distance between the nails. Since this distance is unknown, the number of nails needed remains unknown and these articles are therefore excluded. Further, some articles are provided in zero amounts and are thereby excluded. Moreover, articles that are a specification or a cost of another article were excluded, such as additional cost for customisation of a product or costs for subcontractors. In some cases, an article is included in another article but stated as a separate article in the cost calculation, probably as clarification. These types of articles were therefore excluded from the inventory data. Furthermore, there are articles being excluded in one building element since they are assumed to be included in external documents from the contractor, received during the assessment. This regards articles that were assumed to be included in the prefabricated concrete elements. Finally, articles have been excluded if they were assumed to be unforeseen reparation of another article during production.

In the final list inventory data, 24 building elements were considered with a total amount of 332 articles. This number of articles corresponds to 82 percent of the total number of articles provided in the cost calculation that should be included according to the system boundaries.

3.2.4 Transformation Index

As mentioned in Section 1.5, the tool Transformation Index was developed in the process of this study. This tool was created to enable a structured method and make it possible to document the workload needed, as well as to provide indications regarding the accuracy of the result. As stated in Section 3.2.1, several units in the cost calculation needed to be transformed, by the use of different types of so-called Transformation Steps, to match the unit of the reference material in EcoInvent. The first step in the transformation was to convert the information in the cost calculation to the Bill of Resources. The next step transformed the information in the Bill of Resources into several Building Element Lists. In this Transformation Step, all articles were sorted and summarised per building element.

To perform the unit transformations, there was sometimes a need of assumptions and calculations regarding geometry or density of the articles. These Transformation Steps were performed and documented in the Transformation Lists. Further, the choice of reference material in EcoInvent was another one type of Transformation Step, which was performed for each article or their components. All different types of Transformation Steps made are presented in Table 3.2.

Table 3.2: *Transformation Steps used to process the inventory data.*

Transformation Steps	
Type A	Sorting information
Type B	Summarising information
Type C	Assumptions regarding size and geometry
Type D	Assumptions regarding material composition
Type E	Calculations of mass or volume
Type F	Calculations of material composition
Type G	Choice of reference material

The amount of Transformation Steps, referred to as *Transformation Index (TI)*, is calculated for each article. A higher Transformation Index indicates that several assumptions or calculations have been made to transfer the unit of article in the cost calculation to the unit of the reference material. For every Transformation Step, based on an assumption made, there is a risk of decreased accuracy of the result. A low Transformation Index is also beneficial regarding the workload needed for the collection of inventory data.

Figure 3.1 illustrates the Transformation Steps (TS) made for one of the articles belonging to the ground slab, plastic foil. Two steps, in which the information provided in the cost calculation was sorted, as described above, has already been conducted. Therefore, the first Transformation Step in Figure 3.1 is in fact the third step. In the Building Element list, the unit of the plastic foil is provided in an area, m^2. Since no assumptions had to be made regarding the thickness of the plastic foil, the third step (TS3) was to transform the unit into a volume, m^3. In the fourth step (TS4), the density was assumed and then used in the fifth step (TS5) to transform the unit into a mass, kg. The last step (TS6) was needed since there is no reference material in EcoInvent that is exactly the same as the articles in the cost calculation, and a choice to use packaging film as a reference material was made. These six steps that are needed, to go from the article in the cost calculation to the reference material in EcoInvent, results this specific article having a Transformation Index of six, $TI = 6$.

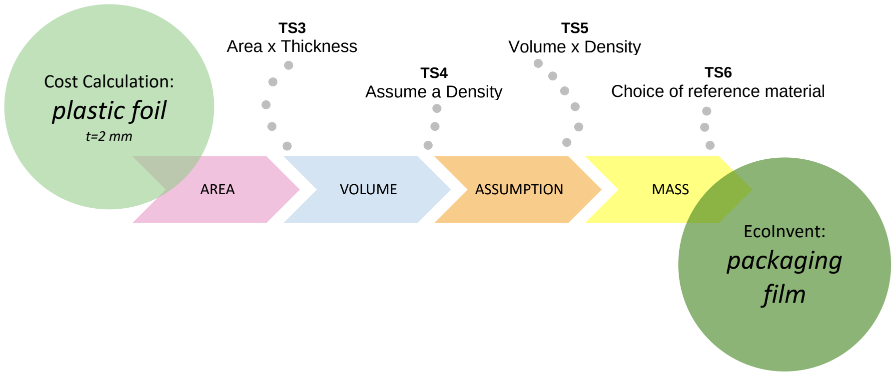

Figure 3.1: *Example of Transformation Steps needed to transform the original article in the cost calculation to the reference material in EcoInvent.*

These types of transformations are made for all articles in the Building Element Lists. Different amounts of Transformation Steps were needed for different articles, which depends on whether the unit found in the cost calculation is the same unit used in EcoInvent. Though, in this case study there have always been a minimum of three Transformation Steps for each article. Firstly, two steps were needed for sorting the data from the cost calculation to the Bill of Resources, where they were sorted per structural component, and then to the Building Element Lists. The third step needed was the choice of reference material in the EcoInvent database. The highest value, a Transformation Index of 35, was found analysing the garage door. This value is the result of a high amount of material components, of which the garage door consists. The garage door consists of 30 different components, and just by paring them with suitable reference materials in EcoInvent equals 30 Transformation Steps. Another article with high Transformation Index is the article that regards painting of the internal walls in the apartments and in the common areas. Even though this article, like the garage door, consists of several components there is another reason behind its high Transformation Index. When transforming this article to match the reference material in EcoInvent, a lot of Transformation Steps were instead needed due to assumptions and calculations of its amount.

Due to the differences in the amount of Transformation Steps needed, an average of the Transformation Index of all articles was calculated. The total average of the Transformation Index in this case study is 8.18, which is shown in Table 3.3 together with some other values of interests. The spread between the smallest and greatest Transformation Index is significant. However, the average and median value indicates that it a lower index is more common among the different articles.

Table 3.3: *Transformation Indexes of interest for the variation analysis.*

Transformation Index	
$TI_{Average}$	8.18
TI_{Median}	6
TI_{Min} (e.g. concrete and reinforcement)	3
TI_{Max} (Garage door)	35

The distribution of Transformation Index for the articles, in respectively building element, is presented in Figure 3.2. The number of the building elements found in the figure corresponds to the numbers found in Table 3.4, which also presents the average for each building element. The size of the dots illustrates the number of articles with a certain Transformation Index. An increased size indicates an increased amount of articles with that index. It is shown in the figure that the majority of the articles have a lower Transformation Index than 15.

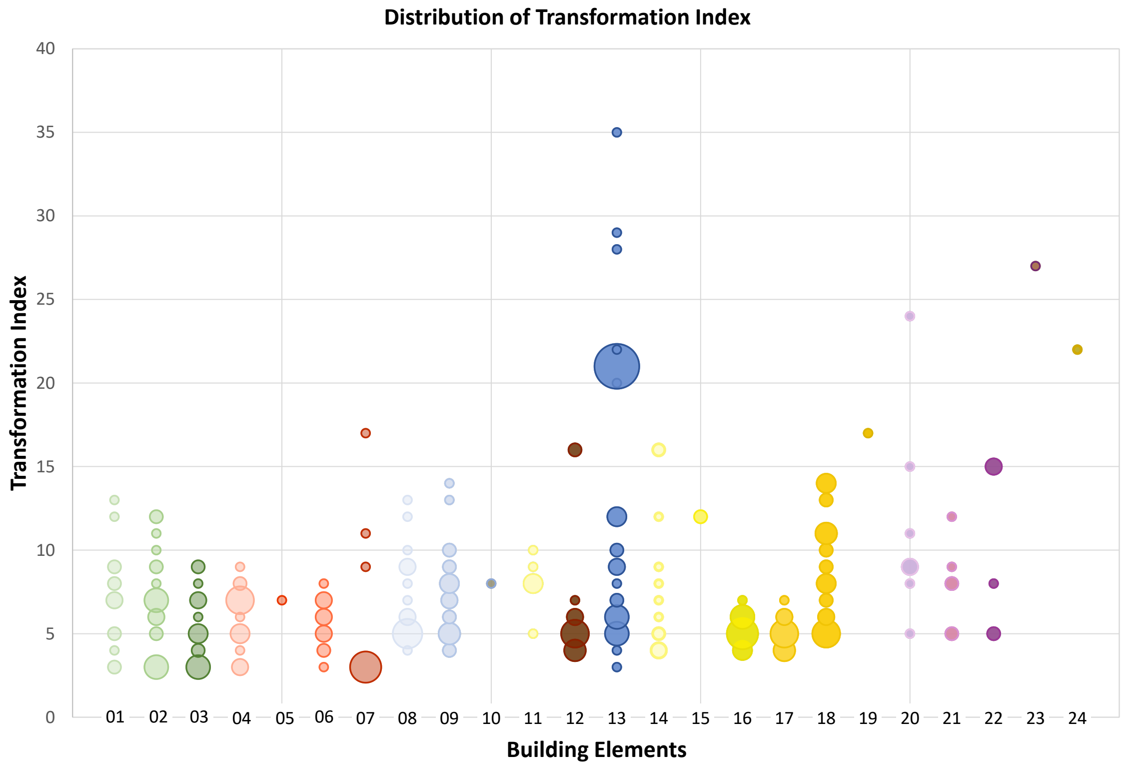

Figure 3.2: *Distribution of Transformation Index for the articles in each building element.*

Table 3.4: *Average Transformation Index for each building element considered in the LCA.*

Building element		$\mathbf{TI}_{Average}$
01	Ground construction, complementary	7.14
02	Ground construction	6.63
03	Ground slab	5.21
04	Structural elements, walls	6.00
05	Prefabricated elements	7.00
06	Structural elements, beams	5.62
07	Steel work	5.15
08	External roof	6.86
09	External roof, complementary	7.41
10	Sheet metal	8.00
11	Building complementary, steel	8.00
12	Structural elements, complementary	6.16
13	Windows and doors	14.08
14	Building complementary	8.00
15	Sub floor	12.00
16	Internal walls	5.19
17	Ceiling	5.00
18	Internal doors and windows	8.72
19	Internal stairs	17.00
20	Surface layer, floor and stairs	11.25
21	Surface layer, walls	7.83
22	Surface layer, roof and false ceiling	10.50
23	Painting	27.00
24	Transportation, elevators	22.00

3.2.5 Origin of Materials

Since several of the articles are missing a manufacturer, the origin of those is unknown. Further, the database EcoInvent are used which consists of generic data that have different origin for different materials and processes. The most common origins for materials in EcoInvent are *Global* (which is an global average), *Rest of Europe* (which is an average for Europe excluding Switzerland), and the average of *Switzerland*. However, for some materials there are also average values of other countries. Since the origin is not known for all the articles in the cost calculation, generic data of Rest of Europe was used in the highest extent possible. For the articles where the origin of the reference could not be set to Rest of Europe, the origins Global, Switzerland, and in some cases other origins, was used instead.

3.3 Life Cycle Impact Assessment

Several assessments were conducted for the building project. Firstly, one assessment where all considered building elements are assembled was performed. This to evaluate which building elements that, to a higher extent, effect the total environmental impact of the buildings. Further, one assessment for each of the considered building element was performed. Through these assessments the impact of the groups of different materials was evaluated. In this section, the results from the conducted assessments are presented. In the figures below, the building elements are grouped in several categories with different colours. Building elements regarding foundation have green colours, the structural elements are red, elements connected to building envelope are blue, surface layers have pink colours and others are yellow.

In the assessment of the total building project, the contribution from each building element has been considered. This to evaluate if some of the excluded elements in a sufficient LCA, according to the environmental certifications BREEAM, LEED or Miljöbyggnad (described in Section 2.3.1) have a noticeable impact.

The building project has been evaluated in 18 environmental impact categories. The total effects of the buildings in the different impact categories are presented in Table 3.5. These values represent the impact per square meter of heated floor area of the building project. Further, the results for each building element are found in Appendix A.

Table 3.5: *Environmental impact of the total building project presented by impact per square meter heated floor area,* A_{Temp}

Entire Building		
Impact category	**Unit**	**Impact/A_{Temp}**
Climate change	kg CO_2 eq	327
Ozone depletion	kg CFC-11 eq	<0.001
Terrestrial acidification	kg SO_2 eq	1
Freshwater eutrophication	kg P eq	<0.1
Marine eutrophication	kg N eq	<0.1
Human toxicity	kg 1,4-DB eq	101
Photochemical oxidant formation	kg NMVOC	1
Particulate matter formation	kg PM10 eq	1
Terrestrial ecotoxicity	kg 1,4-DB eq	<0.1
Freshwater ecotoxicity	kg 1,4-DB eq	3
Marine ecotoxicity	kg 1,4-DB eq	3
Ionising radiation	kBq U235 eq	29
Agricultural land occupation	m^2a	108
Urban land occupation	m^2a	4
Natural land transformation	m^2	<0.1
Water depletion	m^3	644
Metal depletion	kg Fe eq	87
Fossil depletion	kg oil eq	59

The impact of each building element in each impact category, based on the evaluation of the total building project, has also been evaluated. The results regarding the different impacts from the building elements are presented in Figure 3.3. The results show that the building elements that needs to be considered in the LCA in the different building certifications have a great impact in each impact category, such as the foundation, the structural elements and the building envelope. However, other building elements do also have a significant impact in several of the impact categories, such as internal walls and the elevators. Further, the results show that the impact of building elements varies within the different impact categories.

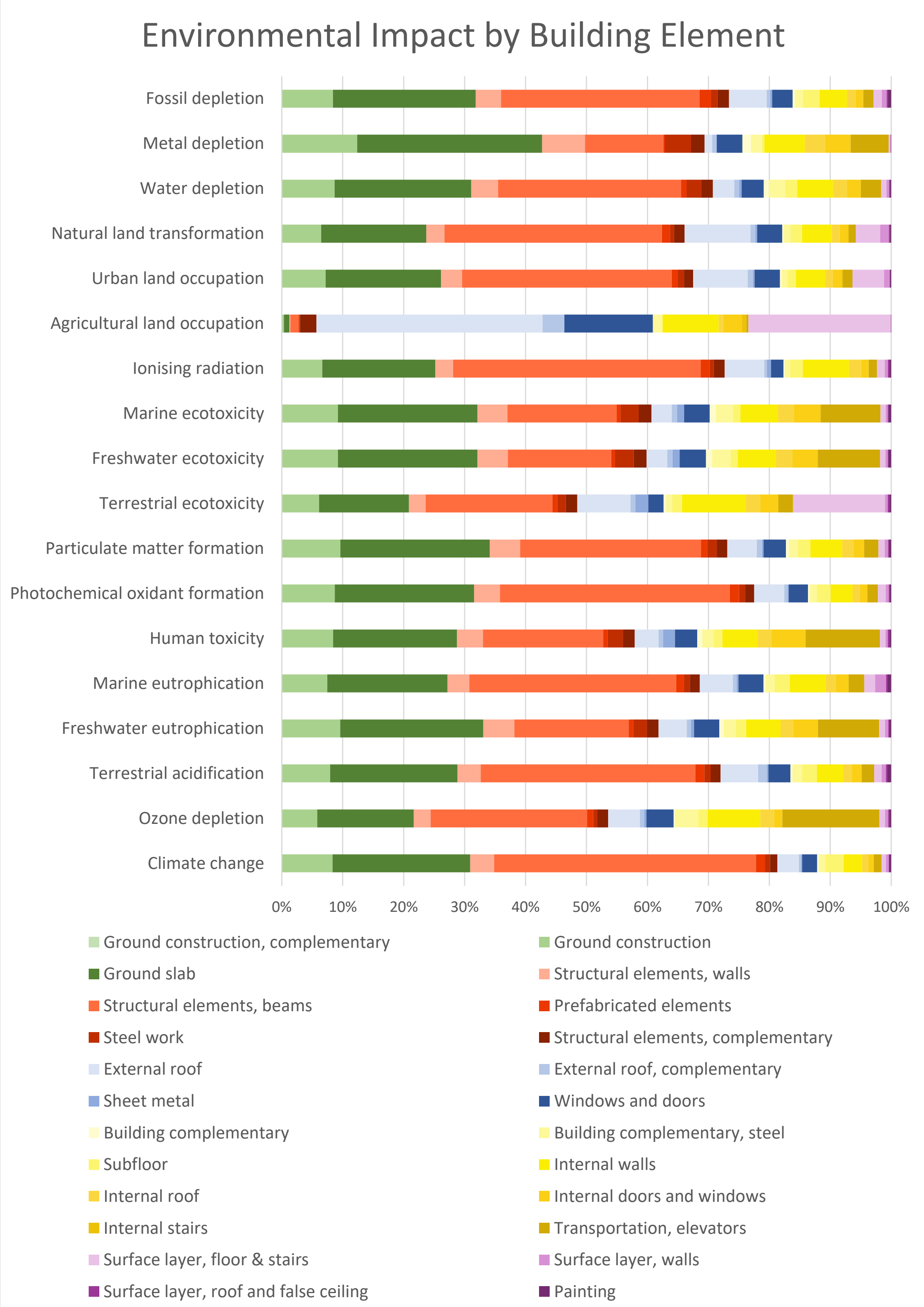

Figure 3.3: *The effect of the included building elements presented for each impact category.*

Figure 3.4 illustrates the impact of each building element on the impact category climate change. As mentioned above, the impact of building elements varies in each impact category. However, the distribution in climate change reflects most of the impact categories. The category that differentiates the most from climate change is agricultural land occupation. A closer look on how the impact on the agricultural land occupation is divided between the different building elements is presented in Figure 3.5. Both figures show how the effect of each building element varies in the two impact categories. Prefabricated concrete elements, ground slab and ground construction are the building elements that dominates the contribution to the impact category climate change. Agricultural land occupation dominates by four building elements, the roof, the surface layer for floor and stairs, windows and doors as well as internal walls.

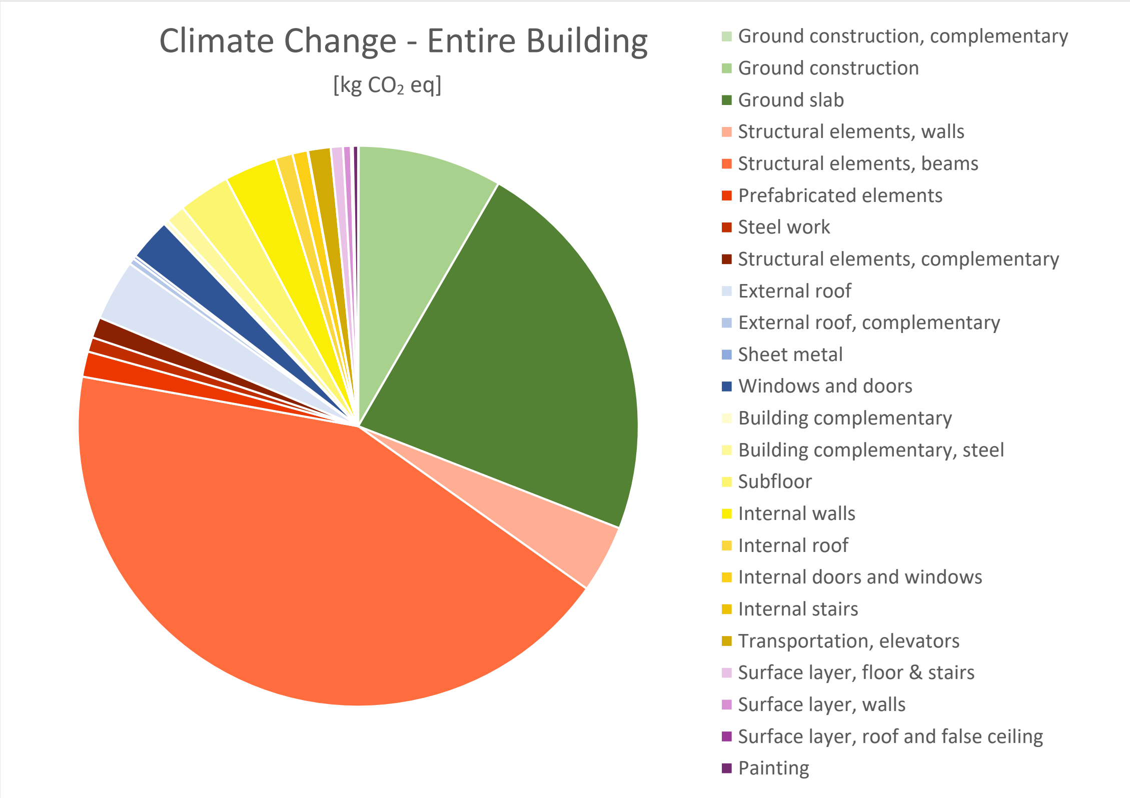

Figure 3.4: *The impact from each building element on the impact category climate change in CO_2 equivalents at midpoint level.*

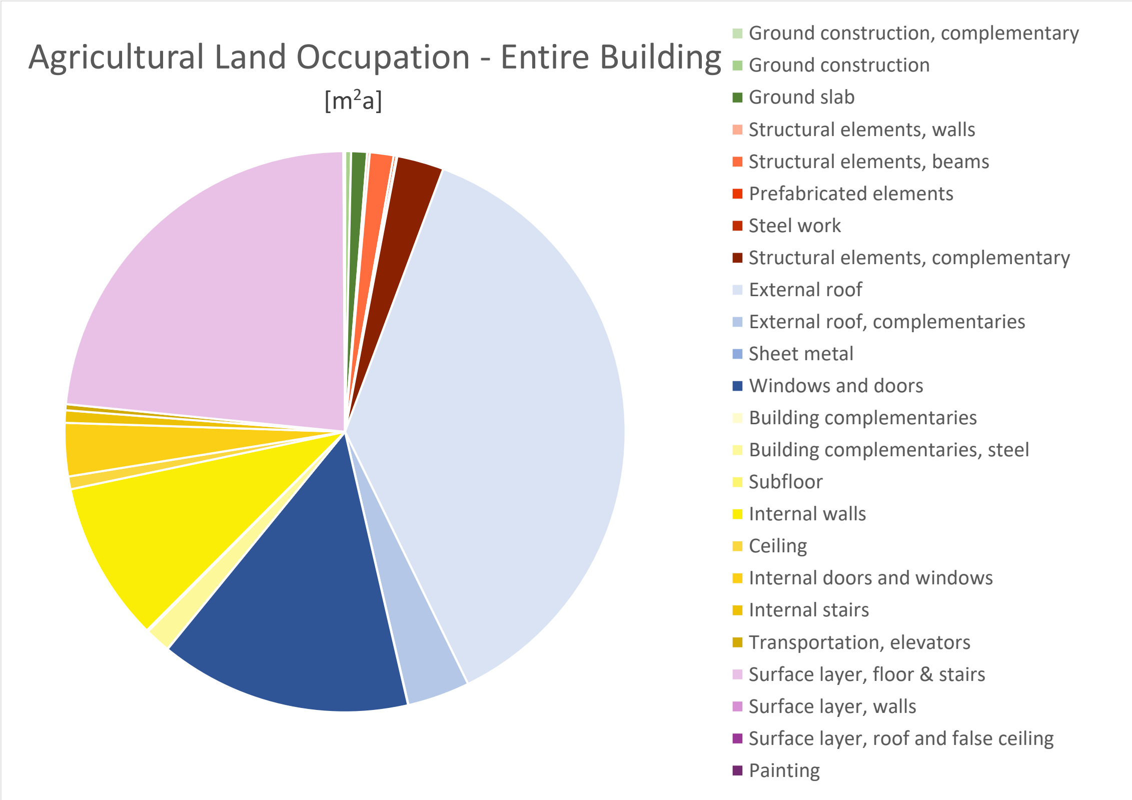

Figure 3.5: *The impact from each building element on the impact category agricultural land occupation in* m^2a *at midpoint level.*

The result from the assessment of each building element is used to evaluate the effect of each type of material. The impact from the same type of material, from all building element, have been summarised and are presented in Figure 3.6. Similar articles are grouped together into different material categories, such as reinforcing steel and screws are both being grouped as *steel*. The evaluation shows that eight groups of materials stand for 97 percent of the total impact in the category climate change. The remaining three percent is divided between several material groups, called *others*. Further, the evaluation shows that *concrete and cement products* stand for 59 percent of the total impact and is therefore the material with the greatest impact. Though, steel does also have a significant impact standing for 25 percent of the total impact of the building.

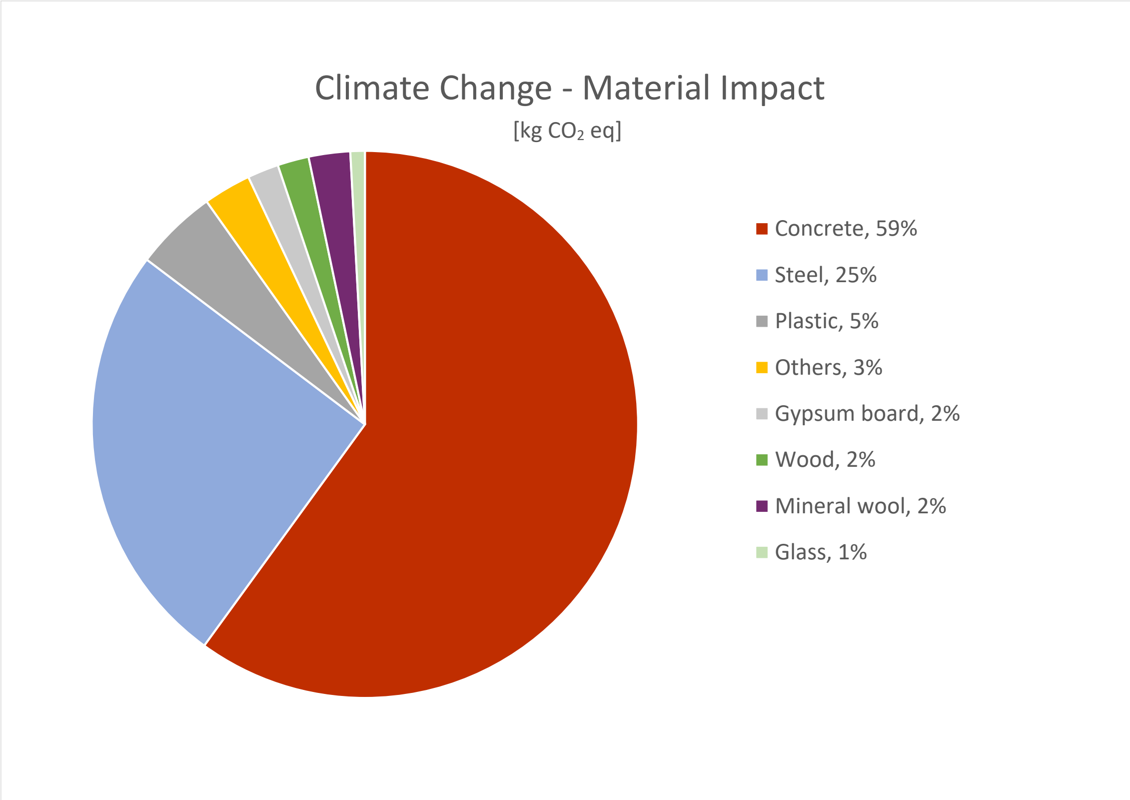

Figure 3.6: *The impact of the groups of materials on the impact category climate change in* CO_2 *equivalents at midpoint level.*

A similar evaluation has been conducted for the impact category agricultural land occupation. In comparison with the category climate change other groups of materials are dominating within this impact category (see Figure 3.7). In this impact category only four groups of materials stand for 98 percent. The greatest impact is from *wood* that stands for 89 percent. The other nine percent are from the material groups *gypsum*, *steel* and *concrete and cement products*.

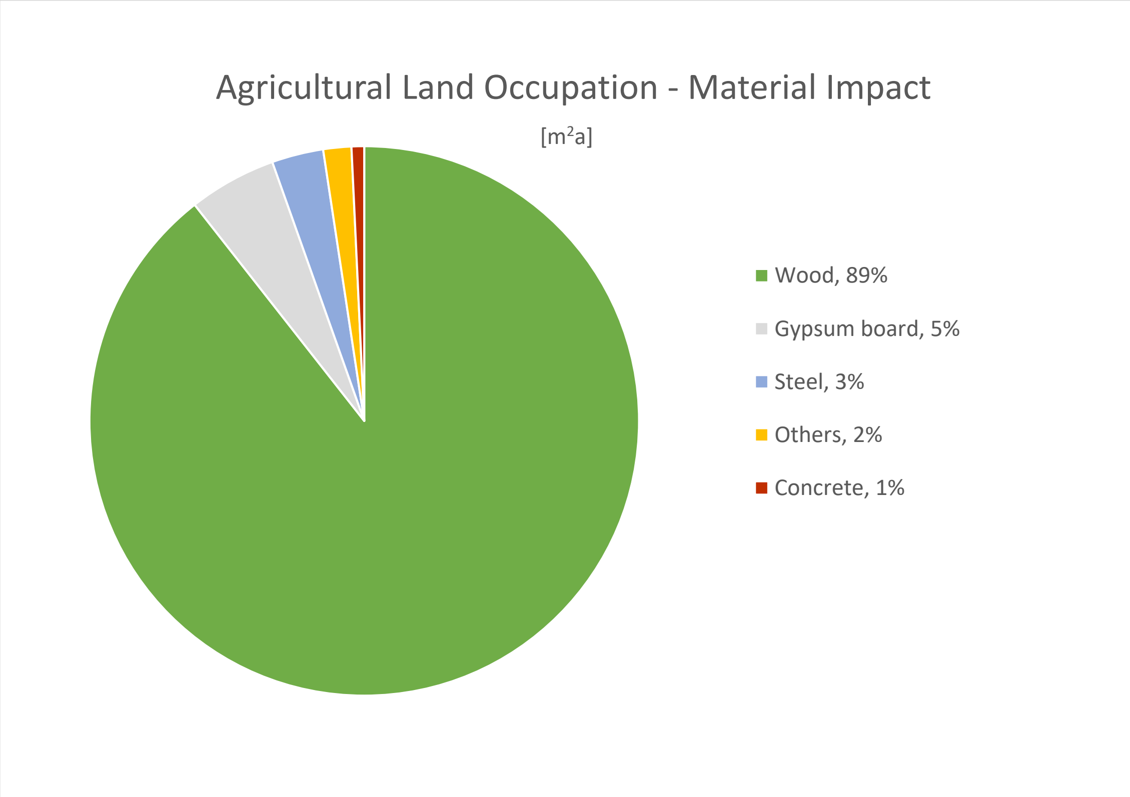

Figure 3.7: *The impact of the groups of materials on the impact category agricultural land occupation in m^2a at midpoint level.*

3.4 Interpretation

This section will interpret the results given in the impact assessment. Further, to evaluate the assessment, several robustness test have been conducted and are presented in this section.

3.4.1 Interpretation of Assessment

Due to climate change being the environmental impact that is in focus within the building industry, it is also in focus in this case study. However, other environmental impact categories were investigated briefly to analyse whether it is of significance to include them in future life cycle assessments. Figure 3.3 shows that the impact from the building elements varies in different impact categories. A building element that has a low impact on the category climate change might have a great impact on another category. One example is the external roof, a building element including a lot of wood. This building element has a low impact in climate change (four percent of the total impact of the building project), but stands for 37 percent of the stressors included in the impact category agricultural land occupation. By including several impact categories, an overall picture of the effect on the environment from the buildings is presented.

Further, the effect of including several building elements is of interest. In climate change the categories foundation, the structural elements and the building envelope stand for 89 percent of the total impact. Other categories, such as surface layers or internal walls, do not have a significant impact on the result. However, regarding agricultural land occupation there is a difference. In this impact category the three main categories (foundation, structural elements and building envelope) of the buildings only stand for 62 percent of the total impact. This indicates the importance of including other building elements, especially within this impact category. As described in Section 3.3, there are differences in which building elements that are having the greatest effect on these two impact categories. The effect of included and excluded building elements is further investigated in Section 3.4.2.5.

The evaluation regarding the impact by the material groups shows that concrete and cement products are the material group with the highest impact within climate change. This is not unexpected since the amount of concrete and cement products is a great part of the total amount of building materials. This since the structural elements, as well as the ground slab are made of concrete. The next greatest impact is from steel, which also is expected due to the high amount of reinforcement in the concrete elements. Further, wood has the highest impact within the category agricultural land occupation. This due to the need of land use to be able to produce wood and a high amount of wood is found in the external roof.

3.4.2 Robustness of Results

To verify the result several checks were conducted, which are presented in this section.

3.4.2.1 Completeness Check

This robustness test will evaluate the completeness of the inventory data used for the assessment. The cost calculation presented by the contractor enabled to construct an comprehensive list of inventory data. However, this list is not complete. Firstly, the scope limited the study to not include installations of any kind as well as the piles. Further, several articles have been excluded during the process due to lack of information, such as articles that did not have enough information to be able to know their right amount. Some articles have not been included since a sub-contractor that has conducted the work and the type and amount of materials is not stated in the cost calculation. However, some of the excluded articles are smaller details, such as fasteners of various kinds, which might not have that great impact of the over all results. However, there are excluded articles that might have a great impact, such as aluminium products provided by a subcontractor. For more information regarding excluded articles see Section 3.2.3.

Despite all the excluded articles the list of inventory data does include comprehensive information compared to other studies that have been observed during the literature review. As described in Section 2.3.1, to fulfil the requirements in the building certifications, only a specific number of building elements need to be considered. In this case study, a higher amount of building elements are considered, thereby increasing the completeness.

Further, the impact assessment method that is used is ReCiPe Midpoint H. This method includes eighteen impact categories that provide a holistic result of the environmental impact of the building project. This is of importance regarding the completeness since, as presented in Section 3.3, the impact of each building element varies in the different impact categories.

Though, there is room for improvements within this study since some type of articles have been excluded. However, the study has a high level of details, with its 332 included articles, and since it is evaluated in several impact categories.

3.4.2.2 Consistency Check

For the processing of the inventory data, a method has been developed. Firstly, all articles were sorted in several lists to organise the information and to achieve an clear view over the inputs of the assessment. Comments on assumptions and exclusions has been saved in the different lists to increase the transparency of the work. However, the lists conducted during the assessments are not included in this document due to the confidentiality of the project's cost calculation. This decreases the transparency of the study.

Further, the Transformation Index, which is a tool to be able to indicate needed workload and risk of decreased accuracy, has been developed. Transformation Steps has been presented to be able to have a consistent way of specifying the Transformation Index for each article. Due to an organised process and with this new index tool, the study has been performed in a methodical way.

3.4.2.3 Data Quality Assessment

For the processing of the inventory data, a method has been developed. Firstly, all articles were sorted in several lists to organise the information and to achieve an clear view over the inputs of the assessment. Comments on assumptions and exclusions has been saved in the different lists to increase the transparency of the work. However, the lists conducted during the assessments are not included in this

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3.4.2.4 Data Quality Assessment

The Transformation Index, described in Section 3.2.4, showed that more than eight Transformation Steps were needed in average to transform the original article to the unit of the reference material in SimaPro. Some of these steps were assumptions, which contributes with some uncertainties in the results and thereby decreases the reliability.

Further, generic data has been used in the study, which results in the temporal and geographical data quality being decreased. The age of the data in EcoInvent has not been evaluated and might not be representative within the building industry today. Moreover, the geographical origin of the reference materials used in the case study varies, but is often chosen to be average data from Switzerland or Rest of Europe. Since the buildings are situated in Sweden, it could be assumed that several of the articles used in the buildings have a Swedish origin. The choice of origin of the materials will effect the result and since the right origin might not be used, the quality of the result is therefore decreased. However, the aim of the study was to analyse the effect of implementing an increased level of inventory data, which is not depending on the origin. It is therefore possible to perform such an analysis with this type of generic data.

Finally, the data is based on a cost calculation that is both detailed and includes some, however not all, manufactures of the different articles. Due to the level of detail, and according to other similar studies [26] stating high quality data, the data used in this study can be considered having a high validity. However, assumptions have been made when information has been missing, and there is therefore room of improvements.

3.4.2.5 Variation Analysis of Level of Details

A variation analysis is performed to analyse the effects of including a high level of details in the list of inventory data. Seven different scenarios (see Table 3.6) will be evaluated and compared to each other in two of the eighteen impact categories in ReCiPe Midpoint H. Firstly, the impact on climate change is evaluated since focus of the study is put on this category. The second impact category considered in this analysis is agricultural land occupation. This since it was the category that differentiated the most from the results of the category climate change in the impact assessment. The variation analysis indicates what effect the use of detailed LCA has on the result.

Table 3.6: *Scenarios used in the variation analysis.*

Scenarios	
A	All articles
B	BREEAM
C	LEED
D	Miljöbyggnad
E	TI=6 cut-off
F	TI=8 cut-off
G	TI=10 cut-off

The first of the seven investigated scenarios is the so-called main assessment, further on referred to as scenario A, based on the contractor's cost calculation including 332 articles. Scenario A is thereafter modified into six new types of scenarios. Scenario B, C and D will respectively include the building elements needed for the different building certifications BREEAM, LEED and Miljöbyggnad. These scenarios represent analyses with vertical cut-offs. As described in Section 2.3.1 the LCA used in LEED should include the building envelope, structural elements and the foundation and in BREEAM the roof, windows, external and internal walls as well as the floors and upper floor slabs should be included. In Miljöbyggnad the foundation and the structure should be included. The last three scenarios, E-G, will include all building elements but only the articles with a Transformation Index lower or equal to a specific value, representing scenarios with horizontal cut-offs. In Scenario E is all articles with a Transformation Index of six or lower included. This value corresponds to the median of all the articles' index. In scenario F the number of included articles increased since the limit is extended to a Transformation Index of eight or lower. This value is chosen due to the mean value that is just above eight. The last scenario, G, includes articles with a Transformation Index of ten or lower. This value is used to exclude articles that require a high workload, such as the garage door and the windows. As stated in Section 3.2.4 is a lower Transformation Index is beneficial in terms of workload needed. The scenario E-G are included to see how the result is effected if the workload is reduced.

Table 3.7 illustrates which building elements that are included in the different scenarios. The table illustrates the amount of articles (in percentage) that are included in each building element in the different scenarios compared to Scenario A. In Scenario E-G the exclusion demands a low amount of alteration since the Transformation Index for the articles is either below or above the chosen limit. However, the exclusion of articles in Scenario B-D is more arbitrary since those exclusions are based on an interpretation of which building elements and articles to include according to the certifications [17] [18] [46] [47]. Further, there are difficulties to know what some of the articles belongs to. One example is sealants used for the exterior walls and windows. In BREEAM, only windows and not doors should be included, which causes issues regarding the sealants. This since there is no information in the cost calculation whether a specific sealant is used for a type of window or a type of door. Thereby the sealants, and other articles with similar uncertainties, were excluded in Scenario B-D.

Table 3.7: *Amount of articles included in each building elements, presented in percentage (%) for each scenario analysed.*

Building Element	**Scenario**						
	A	**B**	**C**	**D**	**E**	**F**	**G**
Ground construction, complementary	100	0	100	100	36	71	86
Ground construction	100	0	100	100	46	75	88
Ground slab	100	0	100	100	68	89	100
Structural elements, walls	100	100	100	100	45	95	100
Prefabricated elements	100	100	100	100	0	100	100
Structural elements, beams	100	100	100	100	69	100	100
Steel work	100	100	100	100	77	77	85
External roof	100	100	100	100	62	71	90
External roof, complementary	100	100	100	0	41	73	91
Sheet metal	100	100	100	0	0	100	100
Building complementary, steel	100	0	0	0	14	71	100
Structural elements, complementary	100	100	100	0	84	89	89
Windows and doors	100	55	100	0	27	33	43
Building complementary	100	42	50	0	50	67	75
Sub floor	100	100	100	0	0	0	0
Internal walls	100	100	0	0	95	100	100
Ceiling	100	0	100	0	94	100	100
Internal doors and windows	100	0	0	0	34	53	66
Internal stairs	100	0	100	0	0	0	0
Surface layer, floor and stairs	100	100	0	0	13	25	63
Surface layer, walls	100	0	100	0	33	67	83
Surface layer, roof and false ceiling	100	0	0	0	33	50	50
Painting	100	0	100	0	0	0	0
Transportation, elevators	100	0	0	0	0	0	0

Table 3.8 presents the amount of included articles in each scenario, based on what is included according to Table 3.7. This to indicate the level of comprehensiveness of the different scenarios. However, the number of included articles only provides an indication on how the amount of workload that is needed. Therefore, total amount of Transformation Steps needed in each scenario are also presented in the Table 3.8. This enables a comparison of the workload needed in the different scenarios. It is shown that the same number of articles not necessary result in the same workload. An example of this Scenario B and E, which both include approximate 170 articles. However, the total amount of Transformation Steps is almost the

double for Scenario B, corresponding to an increased workload.

Table 3.8: *Number of included articles and Transformation Steps for each scenario.*

Scenario	Number of included articles	Total amount of Transformation Steps
A	332 articles	2716 TS
B	172 articles	1486 TS
C	251 articles	2052 TS
D	125 articles	769 TS
E	168 articles	790 TS
F	231 articles	1244 TS
G	264 articles	1550 TS

The total effect on the impact category climate change is calculated for each scenario and presented in Table 3.9. The effect of reducing the amount of included building elements, as well as the level of details, contributed to a decrease of the impact compared to the original study. However, this reduction differs between the different scenarios. Of the three environmental certifications analysed, LEED (Scenario C) is closest to the Scenario A. This since it includes all building element connected to the foundation and structural elements. These building elements include a lot of concrete and cement products, which has a high impact on this climate change.

The result for Scenario E compared to Scenario F and G is significant. This is due to the fact that the prefabricated concrete structural elements have a Transformation Index of seven, and they were therefore excluded in Scenario E. The difference between Scenario F and G is negligible. Further, these two scenarios provide a more accurate result than two of the three certifications.

Table 3.9: *The impact on climate change in each of the scenarios compared to Scenario A.*

Climate change		
Scenario	**Impact** $kg\ CO_2e\ /\ A_{Temp}$	**Amount of Scenario A**
A	327	100 %
B	234	72 %
C	303	93 %
D	275	84 %
E	148	45 %
F	289	89 %
G	294	90 %

The seven scenarios were also evaluated in the impact category agricultural land occupation. The differences between the scenarios distinguish from the differences in the evaluation of the category climate change. The impacts in Scenario E-G are similar to each other, even though the number of articles included differs. Between the three certifications the differences in results are significant. BREEAM (Scenario B) results in the most similar result compared to Scenario A, of all scenarios analysed.

Table 3.10: *The impact on agricultural land occupation in each of the scenarios compared to Scenario A.*

Agricultural land occupation		
Scenario	**Impact** $m^2a\ /\ A_{Temp}$	**Amount of Scenario A**
A	108	100 %
B	101	94 %
C	69	64 %
D	43	40 %
E	59	55 %
F	61	57 %
G	63	59 %

The results in the variation analysis are shown in Figure 3.8. The figure illustrates the variation of the results depending on the scenario.

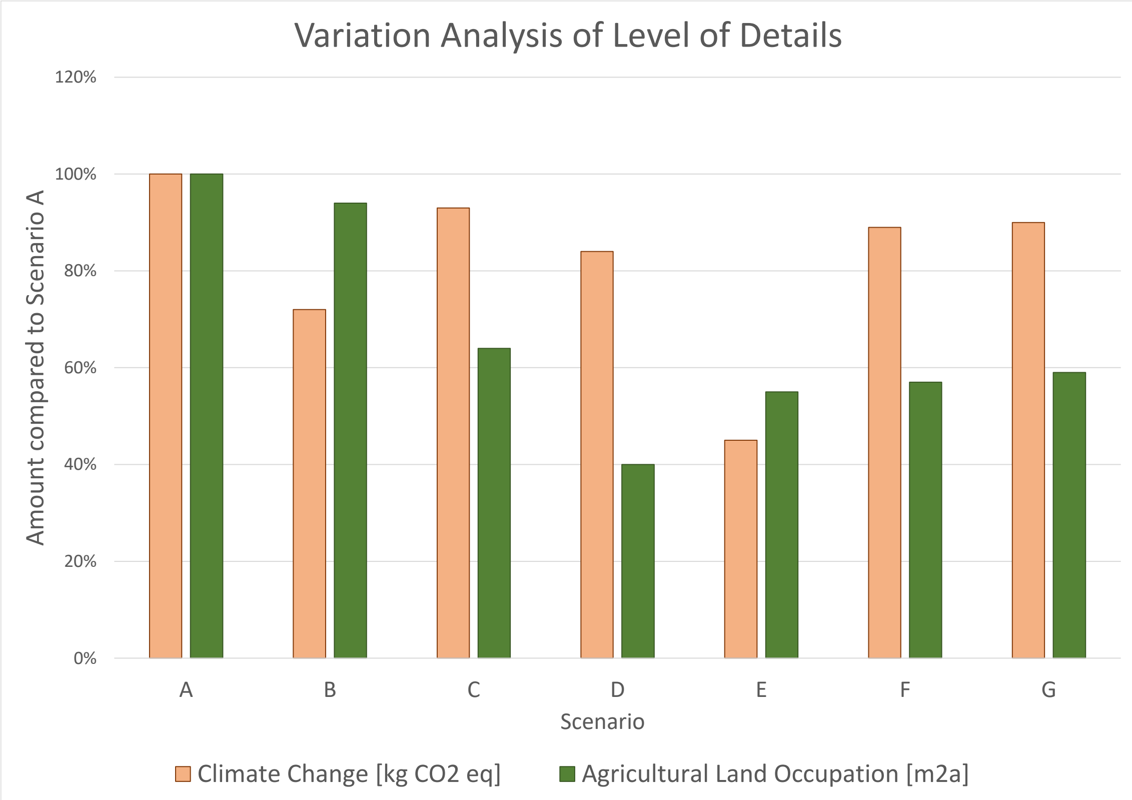

Figure 3.8: *Variations in results for Scenario A-G in the impact categories climate change and agricultural land occupation.*

The variation analysis shows that the level of detail will effect the final result. Depending on the impact category that is evaluated, different categories are more or less suitable. However, none of them is the most suitable approach in both categories.

3.4.2.6 Variation Analysis of Type of Article

The study aimed to be as detailed as possible and through that see how a detailed LCA effects the results. To achieve a high level of detail the choice of reference article was carefully made. If an article had a suitable match in EcoInvent that match was used. This was for example the case for concrete, reinforcement and nails. In other cases, there was no suitable match for the article. Instead product information about the article was found to be able to see what components it is build up of. These components are used in the evaluation in SimaPro. This is for example the case for windows and doors. By using the components instead of the total article, the impact on the environment during the production of the article is neglected. This variation analysis aims to see the effect of using the articles components instead of a similar reference article.

The first analysis regards the terrace doors. In the cost calculation it was stated what brand the terrace doors have. Information about the content of the terrace doors were found in a Swedish database. The components of the terrace doors where used instead of using an existing wooden door with glazed window, which could be found in EcoInvent. This choice was made since the content in the wood and window door was not the same as the content of the actual terrace door. Hence, the choice where made to achieve as high accuracy as possible. The analysis compares the effect from the terrace door build up by their components with the wood and window door found in EcoInvent.

The analysis shows a significant difference between the two cases. The impact from the wooden door with glazed window found in EcoInvent is in average almost three times greater compared to the components used. The production of the door is assumed to be the main reason to the differences in the results. However, there is an opposite change in the impact category agricultural land occupation where the components of the terrace door have the greatest impact.

The second analysis regards the fire gypsum board. For the ordinary gypsum board is a suitable reference article found in the EcoInvent database, but this is not the case for the fire gypsum board. This article is instead, in the same way as the terrace door, build up in EcoInvent by their components. A comparison between the ordinary gypsum board and the fire gypsum board is conducted in the second analysis. The results show that the difference in environmental impact is significant. The normal gypsum board has, in average, an impact that is more than four time greater than the components for the fire gypsum board. However, the gypsum board and the fire gypsum board is not the same article, but it is similar types of products. The significant difference, with a higher environmental impact of the gypsum board, indicates that the process to assemble the components is not a suitable approach. The neglecting of the production phase of the article changed the environmental impact significant. However, also for this article is the increased impact not true for all categories. For the components of the fire gypsum board is the impact higher in the two categories Terrestrial ecotoxicity and Natural land transformation compared to the gypsum board found in EcoInvent.

The last variation analysis investigates in the surface leveling concrete. In the same way as for the other two articles, has the components of the surface leveling concrete been used in the study instead of poor concrete found in EcoInvent. The results show that the differences on the environmental impact is significant here as well. However, is the impact from the different components higher than if a reference material where used. The poor concrete found in EcoInvent does only contribute with an average impact that is approximately one third of the impact from the components.

This variation analysis indicates that the accuracy of using the article's components might not be as accurate as was assumed in the beginning of the assessment.

4

Discussion

The outcome of the case study together with the literature review will be discussed in this chapter to answer the research questions.

4.1 Perform a Detailed Inventory Analysis

One type of outcome from the case study conducted in Chapter 3 regards the work needed to perform the assessment, which is presented in this section.

4.1.1 Needed Information

To be able to perform a comprehensive LCA a lot of information is needed. In this type of study, when only the product stage is considered, it was concluded what type of information that is needed for the articles to be able to include them in the assessment. Foremost, type of material and amount of material is needed. How this information is given is also of importance. One example is the nails that sometimes could be given in number of pieces, which is preferable, or in a length. When the nails are given in a length it refers to the building category that it is used for, it could for example be for fasten the spline. However, it is not stated how many nails that are needed per meter, which can be difficult to know for someone without knowledge about construction of buildings. In what unit an article is presented is therefore of importance. This since it can also ease the transformation from the original article in the cost calculation to the reference material used for the assessment. Further, when an article is given in set it is even more difficult to make assumptions of the exact amount without special knowledge. This since there might be uncertainties what other article or part of the building the set is based upon.

Furthermore, regarding assumptions needed it is beneficial if the brand or manufacturer of the product is stated. Even if generic data is used, and the origin of the article is not needed, knowing the brand or manufacturer will decrease the workload needed to research what product it might be. If specific data is used, knowing the manufacturer is even of greater importance. This since different countries has different energy mixes and therefore different type and amount of emissions. Knowing the origin of the article is also of importance when using generic data. When using reference material within a database such as EcoInvent, knowing the origin might help choosing the most suitable origin of the reference material. Even though there are often many options regarding origin in EcoInvent, choosing the most suitable origin will generate results more fair to reality than by choosing origin by random. However, a manufacturer might have factories in different countries. This might lead to assumptions based solely of the nationality of the manufacturer causing less accuracy of the results. Further, even if a manufacturer has all production of a certain product in one country, there might be two or more factories in this specific country. These factories might however use different type and amount of energy for the production, due to where in the country the factory is placed and how energy efficient the production line is. Receiving the correct input for the assessment might therefore be almost impossible due to this complexity.

Moreover, another reason why knowing the manufacturer is beneficial is that different manufactures might have different content in their products. However, in some cases the content, or the exact amount of content, is not presented due to the manufacture's confidentiality. This decreases the accuracy of the result even though the comprehensive information is provided. Further, knowing the brand of the product is preferable. This since there can also be a difference in content, sizes and density of similar products from different manufacturers, or even from the same manufacturer.

To summarise, if conducting an LCA with inventory data based on a comprehensive cost calculation, the amount of assumptions having to be made would decrease knowing the manufacturer or brand of the article, where in the buildings the article will be used and having the article defined in the same unit as the unit of the reference material. Regarding the later it could alternatively be enough knowing the dimensions and density of the article to be able to make calculations transforming the unit of the article to the same unit as the unit of the reference material.

4.1.2 Practicability

To perform this type of LCA, based on a detailed list of articles a lot of time is needed. A lot of the work has been put on doing research of the different products that is used. This to be able to transform units and to find the content of the material of the article. A lot of assumptions where needed, both regarding sizes and content. These assumptions have increased the uncertainties of the results. Regarding articles not found in the EcoInvent database, their components where instead used. This in particularly might have decreased the overall environmental impact since the production of those articles is not included, only production of the components.

To be able to visualise the conducted work a Transformation Index was presented, see Section 3.2.4. This index gives information on how many steps and assumptions that where needed to go from the original article to the reference material in EcoInvent. However, it does only show number of steps and possible assumptions, not how long it took to do the research, to receive information needed for the transformations.

Further, the Transformation Index also provides an indication of the accuracy of the results. A higher index signifies, as mentioned above, that several assumptions, calculations or choices of reference material were needed for the transformation. There was a higher need of Transformation Steps for articles that were not directly found in EcoInvent. Instead, as mentioned above, the components of the article were used leading to the production of the article is neglected. To be able to include the production more assumptions are needed, and the Transformation Index would increase even higher.

However, not all articles needed Transformation Steps, except for the three required ones. Though, these articles stand only for 20 % of the 332 articles used in the assessment. This number indicates that the accuracy might not be as high as is desirable. Analysing the number of articles with a need of assumptions can provide answer to whether a high index is due to assumptions or several calculation steps.

Different types of information can be used for the assessment. In the case study generic data was used for the analyse. Information regarding the articles was collected from BMAs. These types of documentation do rarely include the emissions during the production, instead they only provide the content of an article. A more accurate analysis would be provided if EPDs were used instead since they have more information included. However, based on the case study of this thesis, it seems that EPDs are less common than BMAs. This will stay a problem regardless of what type of methodologies that will be developed to simplify the LCA process in the future. Regardless of the level of details and the comprehensiveness of the LCA, the accuracy of the results might be decreased if the reference material used is far from the materials in the inventory data. As mentioned in Section 2.3.5, IVL is developing a tool consisting of Swedish building materials for construction the foundation and structural elements. Using this data might have provided more accurate results in the case study. However, since this tool is not compatible with the used soft-ware SimaPro, more time would have had to be spent creating own processes including this information. Even if this input would be created manually, there is still no guarantee that it is more accurate.

When processing the inventory data, it was concluded that the amount of information in the cost calculation was not enough to be able to include all articles. This was the case even though the project was a partnering project and all information should be visible for both the commissioner and the contractor. However, complete transparency between the two parts is not enough in this case. This since subcontractors are involved and the material they are using are not stated in the cost calculation. Further, some articles were, as previous discussed, excluded due to difficulties to find suitable matches in the EcoInvent.

Finally, since the process of conducting the lists of inventory data (Building Element Lists and Transformation Lists) was complex, the result might have been influenced by the human error. During the process the research on different materials become better. New sources to find information on where found and the knowledge regarding building materials where increased. This led to better assumptions after a while and that the building elements conducted in the beginning of the study might not have the same quality as the ones conducted later. A well-structured process for the assessment is therefore of great importance to receive results with higher accuracy.

4.1.3 Previous Knowledge

As mentioned in the previous section, a lot of work was needed to gathering inventory data for the assessment. This workload could be reduced if more knowledge about the building process had been gain before the study. An experienced person would be able to do a more accurate analysis with a bit less workload. This is due to that there is a lot of specific words and expression used for the building industry that is used in the lists. With more experience the expression will be easier to understand, and the assumptions will be more accurate. Further, the articles in the cost calculation are presented in Swedish and the reference material in EcoInvent is in English causing a need of translation. This need contributes with the need of knowledge of building industry terms in both languages to be able to make an accurate analysis. Dictionaries have been used, but they often lack in the amount of building industry terms. This since one article might have several names. Even by using a dictionary adapted for the building industry, there is hardly possible for it to cover all articles within a building. The experience is not only needed regarding the building industry but also, as described by Glaumann, Malmqvist, Peuportier, *et al.* [31], in the software.

Further, the choice of what to include or not is also influenced by how much previous, as well as project specific, knowledge the person performing the LCA has. Some articles can be difficult to know if they should be excluded or not regarding to the chosen system boundaries. This could for example be the construction plywood that sometimes is used as a building material but at other times is used as a mould and therefore is demolished before the buildings are completed. Another example is, article that appeared to be included in other articles or additional documents received from the contractor. To be able to notice if one article appears twice, requires knowledge of the articles that is included in the buildings and the amount of each type of article.

It was discovered during the process that it was easier to perform the assumptions and calculations after time. This since the knowledge were increased and new platforms to search for information were found. Therefore, it is concluded that the performer of the LCA can benefit from previous performed studies.

Another possibility is, as in other fields before, involving consultants to perform life cycle assessments on buildings. Consultants will have the opportunity to create their own database with information regarding commonly used building materials. Further, they collect new knowledge from each project they are involved in and will get front edge competence within this field. Moreover, involving consultants might be the only way for smaller companies to be able to perform LCA if it ought to be mandatory according to the proposals from Boverket [3] and Upphandlingsmyndigheten [5]. This since it might be demanding considerable resources.

4.2 Full LCA

The concept full LCA has no single definition. Results from two different full LCA might therefore not be comparable since they might be "full" in different ways. The common denominator for the different analysis is that they have been more thorough than the previous performed life cycle assessments on buildings.

With this in consideration it is of interest to evaluate whether the case study could be defined as a full LCA. According to the reasoning of Oregi, Hernandez, Gazulla, *et al.* [23] and Cuéllar-Franca and Azapagic [24] should an LCA include all stages to be defined as a full LCA. The case study does only consider the product stage and not the total life cycle from cradle to grave. However, this case study achieves both requirements that Vitale and Arena [26] and Emami, Heinonen, Marteinsson, *et al.* [25] mentions when defining a full LCA. The case study has a high level of details in the inventory list, both regarding included building elements and number of articles. Further, the case study does also show the impact on several environmental impact categories.

The case study only includes the product stage and thereby a great part of the buildings' life cycle is neglected, and all types of installation were excluded, decreasing the accuracy of the results. With this in consideration, it could be questioned if the case study can be considered as a full LCA. However, the study is performed in a thorough way regarding included articles and impact assessment methods. Therefore, it can be used to answer the aim of the report regarding effects of full LCA.

4.3 Effects on the Result by a Full LCA

A full LCA regarding number of included impact categories contributes with a broader understanding of the environmental effect of the building project. The study shows that the impact one building element or building material have within one impact category might not be the same as in another category. The differences between the result of climate change and of agricultural land occupation where significant. The variation where shown both in which building elements that had the greatest impact, as well as how the impact was influenced by the cut-off of articles based on the Transformation Index. If only one category is considered, this often being climate change in building LCA, important information might be left out. To achieve a fair overall picture of the environmental impact from the buildings it is important to include more than one impact category. As mentioned in Section 2.3.2, Upphandlingsmyndigheten [5] has requested that LCA on a building should include other impact categories but climate change since climate change is not the only important category for a sustainable environment. This is confirmed by the results of this thesis, showing the large differences between climate change and agricultural land occupation.

The variation analysis in Section 3.4.2.5 showed that two methods that included the same number of articles might not have the same workload since the amount of Transformation Steps might vary. If comparing the scenarios based on certifications with the ones with cut-offs based on Transformation Index, the ones with a lower workload in comparison to number of articles are the ones based on Transformation Index. Regarding the workload, it could be beneficial to base the cut-offs on a limit regarding Transformation Index. However, as was illustrated in Section 3.4.2.5, that type of cut-off is not always the most suitable regarding the effects on the result. Though, it could provide an economical incentive for companies to perform life cycle assessments on buildings including a higher level of inventory data.

Regarding the three environmental certifications BREEAM, LEED and Miljöbyggnad, based on vertical cut-offs, the results compared to the original study (Scenario A) varied. In the impact category climate change, LEED (Scenario C) was the most similar to Scenario A. However, this is the scenario is including the highest number of Transformation Steps and therefore is the one with the highest estimated workload of the three. The effect on the results for Scenario F and G, based on horizontal cut-offs, were similar to each other (a difference of one percent) even tough different workload were needed. However, to include articles with a Transformation Index of nine or ten does not increase the accuracy of the results to such extent that it might justify the increase in workload. Though, Scenario F is the more suitable of these two since the effect on the result is minimal even though the workload is reduced. Further, Scenario F can also be compared to Scenario C, where the difference in the results is four percent. These four percent results in the workload being reduced in term of a reduction of 800 Transformation Steps. The question then rises, whether an improvement of the accuracy by a couple of percentages weight higher than an increased workload when the robustness of the results often is uncertain, especially when using generic data.

In the impact category agricultural land occupation, Scenario B (BREEAM) distinguishes from the other scenarios by having the most similar result compared to Scenario A. Further, the analysis shows that the effect on the result in Scenario E-G is similar to each other. However, the cut-off for the Transformation Index needs to be with a higher value than in climate change to give a more similar result to Scenario A. Though, since most of the different impact categories in ReCiPe midpoint H are similar to the impact category climate change, a scenario with results close to Scenario A in this specific impact category might be the most suitable to choose.

As presented in Section 2.3.3, the possibility to make environmentally friendly choices in the project decrease with time during the project. Boverket [19] presents therefore the value of include LCA early in the project. To implement LCA in an early stage is also included in the environmental certifications BREEAM and LEED [17] (see Section 2.3.1). However, to be able to perform an LCA with detailed inventory data a lot of information is needed. Early in the project this type of information, such as type of material or specific manufacture, might not have been decided. This makes it difficult to perform a comprehensive assessment, in regard to inventory data, in an early stage of the project. One option could be to perform a simplified LCA in the early stages of the project and later develop the LCA as the project continues and more details is defined. Alternatively, if performing enough comprehensive assessments might result in gaining enough knowledge of the approximate effect of including a high amount of building details in the list of inventory data to use as a supplementary addition to a simplified LCA.

4.4 Robustness of the Result

Several assumptions and exclusions were conducted during the process of the study. This combined with the actual origin of the materials not being taken into consideration contributes to a decrease in the accuracy of the results. However, the aim of the study was to investigate in the implication of a full LCA. The implication is possible to address even if the result of the impact assessment of the case study not is as close to reality as desirable. The conclusion taken from the process of conducting the LCA can therefore be assumed to be robust.

The second variation analysis regarding choice of articles (see Section 3.4.2.6), indicated uncertainties in the results. In some cases, components of an article were used to be able to find similar reference material in EcoInvent, when the article itself had no suitable match. This with the aim to increase the accuracy of the result of the assessment. However, the variation analysis showed that the impact from the articles where their components were used, compared to when a similar product in the database was used, were significant. For two of the tested articles, the wooden door with glazed window and fire gypsum board, did the result showed that the impact from the components were lower than if a similar article were used instead. However, this was not the case for the surface levelling concrete, were the impact were higher for the poor concrete found in EcoInvent compared to when the components were used. This shows that it can be concluded that no conclusion can be drawn whether it is better to use a similar article or to use the components of an article. Though, it can result in differences in depletion of specific raw materials, cause local emissions or have other impacts, which not have been analysed in this thesis.

4.5 Learning Outcomes of Performing a Full LCA

The case study showed the effect of number of included building elements. When excluding building elements, or articles above a certain Transformation Index, some impact is thereby neglected. However, as mentioned above, it could be questioned whether the increase of included articles provides an improved accuracy justifying the enlarged workload. It could also be questioned whether this case study could be used as a guideline to simplify future life cycle assessments based on workload. The case study shows that the importance of including all building elements varies depending on the impact category being evaluated. Hence, there is no single solution on which inputs to include or exclude based solely on workload, simplifying the work needed in life cycle assessments. However, it can be concluded that in this study, articles with a Transformation Index higher than eight are not significant to the results when only considering climate change. The main contributor for this category was the group of material regarding concrete and cement products. Articles with high Transformation Index did in general not include these materials and therefore they do not contribute significantly to this impact category.

When analysing the effect on agricultural land occupation in different scenarios, none of the scenarios with a cut-off based on Transformation Index were similar to Scenario A. Therefore, simplifications based on Transformation Index will lead to a significant decrease in accuracy for this impact category. However, if comparing the results to how LCA in commonly used within the building industry today, the results of Transformation Index cut-offs might still provide higher accuracy.

For future assessments it is important to consider that a decrease in the number of articles included not necessary will lead to a decrease in workload. This since the workload depends on the amount of needed Transformation Steps rather than the number of included articles. Further, the cut-offs that were suitable in this study might not be the optimal cut-offs in other cases. Finally, if using a cost calculation as a source for inventory data, the Transformation Indexes for its different articles will vary depending on the amount of information provided. This since the information will influence the need of assumptions.

5

Conclusion

There is no single definition of a full LCA. Previous life cycle assessments claim that they are performing a full LCA have performed it in different ways. Either by including a high amount of different impact categories, including a comprehensive list of inventory data or by including all stages of the building's life cycle. Though, the common denominator is that they all, in some way, include more parameters than general.

The case study in this thesis was questioned regarding if it can be named as a full LCA. This since only the product stage of the building project were considered and all types of installations and articles connected to pile works were excluded. However, the level of details of the inventory data was comprehensive with its 332 included articles. During the process of the assessment it was concluded that performing an LCA at such a detailed level requires a great amount of effort as well as previous knowledge. The work needed could be decreased by knowledge of the building industry in general as well as the specific project being analysed. Performing an LCA with a high level of detail is a time-consuming process. A well-structured process for the assessment is therefore of great importance to receive results with higher accuracy.

During the case study the new tool Transformation Index were invented. This tool enabled a structured method where every step of the process was documented. Further, it provides information regarding the need of assumptions and calculation steps for each article. A lower index is preferable, both in terms of needed workload and accuracy of the results.

The case study evaluated the building project's impact in several impact categories. It was shown that the effect of each building element varied in the different categories. Therefore, it is of interest to evaluate buildings in more categories than only the climate change as often is the case today. This to get the bigger picture of the buildings' entire impact on the environment.

The case study showed that the effect on the result is depending on the comprehensiveness of the inventory. Different scenarios of simplified assessments were compared to a scenario including all articles in the list of inventory data. These different simplified scenarios were based on the environmental certifications BREEAM, LEED and Miljöbyggnad, as well as different cut-offs based on Transformation Index. The accuracy of the scenarios varied depending on which impact category that was investigated. Further, it was concluded that a decrease in the number of articles not necessary decrease the needed workload. Instead it is more important to focus on the amount of needed Transformation Steps.

From only one case study it is difficult to conclude specific simplification for future LCA. However, the study shows that there is an effect based on the comprehensiveness of the inventory data, and it can be concluded that it is all about the details.

The thesis has explored the use of full LCA within the building industry. However, there is more steps needed to be able to fully implement LCA in the building industry. Suggestions on further investigation is to the develop the Transformation Index. As it is used now, assumptions have the same effect on the index as other steps, such as sorting or calculations, which does not influence the accuracy. The tool could be developed in some way that the accuracy of the result is reflected in the index. Another suggestion is to further investigate in the effect of origin of the reference material compared to the actual origin of the article. This to see the effect of using generic data compared to specific data.

Bibliography

[1] A. Bjørn, M. Owsianiak, C. Molin, and M. Z. Hauschild, "LCA history", in *Life Cycle Assessment: Theory and Practice*, Cham: Springer International Publishing, 2017, pp. 17–30. DOI: 10.1007/978-3-319-56475-3{_}3.

[2] M. Buyle, J. Braet, and A. Audenaert, "Life cycle assessment in the construction sector: A review", *Renewable and Sustainable Energy Reviews*, vol. 26, pp. 379–388, Oct. 2013. DOI: 10.1016/J.RSER.2013.05.001.

[3] Boverket, *Klimatdeklaration av Byggnader: Förslag på metod och regler*, Karlskrona, 2018. [Online]. Available: https://www.boverket.se.

[4] J. Heinonen, A. Säynäjoki, J.-M. Junnonen, A. Pöyry, and S. Junnila, "Pre-use phase LCA of a multi-story residential building: Can greenhouse gas emissions be used as a more general environmental indicator?", *Building and Environment*, vol. 95, pp. 116–125, 2016. DOI: 10.1016/j.buildenv.2015.09.006.

[5] Upphandlingsmyndigheten, "Remissvar på Boverkets rapporter 2018:22", Näringsdepartementet: Avdelningen för bostäder och transporter, Stockholm, Tech. Rep., 2018. [Online]. Available: https://www.regeringen.se/4af96d/contentassets/f0d932955d3542fea01d9a744b94dbbe/upphandlingsmyndigheten.pdf.

[6] H. Baumann and A.-M. Tillman, *The Hitch Hiker's guide to LCA: An orientation in life cycle assessment methodology and application*, 1:9. Lund, Sweden: Studentlitteratur AB, 2015.

[7] A. Lewandowska, A. Noskowiak, G. Pajchrowski, and J. Zarebska, "Between full LCA and energy certification methodology - a comparison of six variants of buildings environmental assessment", *The International Journal of Life Cycle Assessment*, vol. 20, no. 1, pp. 9–22, 2015. DOI: 10.1007/s11367-014-0805-3.

[8] R. G. Hunt, T. K. Boguski, K. Weitz, and A. Sharma, "Case studies examining LCA streamlining techniques", *The International Journal of Life Cycle Assessment*, vol. 3, no. 1, pp. 36–42, Jan. 1998, ISSN: 0948-3349. DOI: 10.1007/BF02978450. [Online]. Available: http://link.springer.com/10.1007/BF02978450.

[9] M. Erlandsson, T. Malmqvist, K. Jelse, and M. Larsson, *Livscykelanalysbaserade miljökrav för byggnadsverk: En verktygslåda för att ställa miljökrav*. Stockholm: IVL Svenska Miljöinstitutet, 2018. [Online]. Available: www.ivl.se.

[10] R. Salomone, *Product-oriented environmental management systems (POEMS) : improving sustainability and competitiveness in the agri-food chain with innovative environmental management tools*. Springer, 2013, ISBN: 9400761163.

[11] *Environmental management – Life cycle assessment – Requirements and guidelines*, SS-EN ISO 14044:2006, Swedish Standards Institute.

[12] H. Baumann and A.-M. Tillman, *The Hitch Hiker's Guide to LCA: An orientation in life cycle assessment methodology and application*, 1:9. Lund, Sweden: Studentlitteratur AB, 2004.

[13] B. Weidema, H. Wenzel, C. Petersen, and K. Hansen, "The Product, Funtional Unit and Reference Flows in LCA", Danish Environmental Protection Agency, Tech. Rep., 2004. [Online]. Available: http://lca-center.dk/wp-content/uploads/2015/08/The-product-functional-unit-and-reference-flows-in-LCA.pdf.

[14] Boverket, *Miljödata*, 2019. [Online]. Available: https://www.boverket.se/sv/byggande/hallbart-byggande-och-forvaltning/livscykelanalys/miljodata-och-lca-verktyg/miljodata/.

[15] R. Carlson and A.-C. Pålsson, *Livscykelanalys - Ringar på vattnet*, 1st ed. Stockholm: SIS Förlag AB, 2008.

[16] *Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method*, SS-EN 15978:2011, Swedish Standards Institute.

[17] Boverket, *Miljöcertifieringssytem och LCA - Boverket*, 2019. [Online]. Available: https://www.boverket.se/sv/byggande/hallbart-byggande-och-forvaltning/livscykelanalys/miljocertifieringssystem-och-lca/.

[18] BRE Global Ltd., *Mat 01 Life cycle impacts*, 2012. [Online]. Available: https://www.breeam.com/BREEAM2011SchemeDocument/content/09_material/mat01_general.htm.

[19] Boverket, *Vilka mervärden ger en LCA?*, 2019. [Online]. Available: https://www.boverket.se/sv/byggande/hallbart-byggande-och-forvaltning/livscykelanalys/vilka-mervarden-ger-lca/.

[20] One Click LCA, *Life Cycle Assessment Guide for Green Building experts - Part 1*. [Online]. Available: https://www.oneclicklca.com/life-cycle-assessment-explained/.

[21] B. Ströbele and T. Lützkendorf, "Communicating environmental information: rethinking options for construction products", *Building Research & Information*, vol. 47, no. 6, pp. 681–696, Aug. 2019. DOI: 10.1080/09613218.2018.1521191.

[22] *Environmental management – Life cycle assessment – Principles and framework*, SS-EN ISO 14040:2006, Swedish Standards Institute.

[23] X. Oregi, P. Hernandez, C. Gazulla, M. Isasa, X. Oregi, P. Hernandez, C. Gazulla, and M. Isasa, "Integrating Simplified and Full Life Cycle Approaches in Decision Making for Building Energy Refurbishment: Benefits and Barriers", *Buildings*, vol. 5, no. 2, pp. 354–380, May 2015. DOI: 10.3390/buildings5020354.

[24] R. M. Cuéllar-Franca and A. Azapagic, "Environmental impacts of the UK residential sector: Life cycle assessment of houses", *Building and Environment*, vol. 54, pp. 86–99, Aug. 2012. DOI: 10.1016/J.BUILDENV.2012.02.005.

[25] N. Emami, J. Heinonen, B. Marteinsson, A. Säynäjoki, J.-M. Junnonen, J. Laine, S. Junnila, N. Emami, J. Heinonen, B. Marteinsson, A. Säynäjoki, J.-M. Junnonen, J. Laine, and S. Junnila, "A Life Cycle Assessment of Two Residential Buildings Using Two Different LCA Database-Software Combinations: Recognizing Uniformities and Inconsistencies", *Buildings*, vol. 9, no. 1, p. 20, 2019. DOI: 10.3390/buildings9010020.

[26] P. Vitale and U. Arena, "An attributional life cycle assessment for an Italian residential multifamily building", *Environmental Technology (United Kingdom)*, vol. 39, no. 23, pp. 3033–3045, Dec. 2018. DOI: 10.1080/09593330.2017.1371252.

[27] Swedish University of Agricultural Sciences, *Vad är livscykelanalys?*, 2019. [Online]. Available: https://www.slu.se/institutioner/energi-teknik/forskning/lca/vadar/.

[28] Teknikhandboken, *Byggvarudeklaration - Miljövarudeklaration.* [Online]. Available: http://www.teknikhandboken.se/handboken/takets-utformning-och-planlosning/material-och-produktval/byggvarudeklaration-miljovarudeklaration/.

[29] Lund University, *Databases A-Z.* [Online]. Available: http://emedia.lub.lu.se/db/info/553.

[30] SundaHus, *SundaHus Miljödata: Verktyget för effektivt och resultatorienterat arbete med medvetna materialval.* [Online]. Available: https://www.sundahus.se/tjanster/miljodata/.

[31] M. Glaumann, T. Malmqvist, B. Peuportier, C. Wetzel, S. Scarpellini, I. Zabalza, S. Díaz de Garayo, H. Staller, G. Krigsvoll, E. Stoykova, S. Horváth, Z. Szalay, and V. Degiovanni, "Riktlinjer för LCA beräkningar i tidiga byggnadsskeden", Enslic building, Tech. Rep., 2010. [Online]. Available: http://www.diva-portal.org/smash/get/diva2:478583/FULLTEXT01.pdf.

[32] IVL Svenska miljöinstitutet, *Byggsektorns miljöberäkningsverktyg*, 2019. [Online]. Available: https://www.ivl.se/sidor/vara-omraden/miljodata/byggsektorns-miljoberakningsverktyg.html.

[33] A. Proctor and Royal Society of Chemistry (Great Britain), *Alternatives to Conventional Food Processing*, 2nd ed. Cambridge [England]: Royal Society of Chemistry, 2018.

[34] A. Kylili and P. A. Fokaides, "Construction Materials for the Urban Environment: Environmental Assessment of Life Cycle Performance", in *Handbook of Ecomaterials*, Cham: Springer International Publishing, 2019, pp. 2143–2175. DOI: 10.1007/978-3-319-68255-6{_}133.

[35] Stockholms stad, "Energianvändning och LCA-beräkningar i byggprocessen", Stockholm, Tech. Rep., 2015. [Online]. Available: https://insynsverige.se/documentHandler.ashx?did=1809007.

[36] S. Karaman Öztaş, "The limitations of LCA methodology towards sustainable construction materials", in *Engineering Proceedings of 3rd International Sustainable Buildings Symposium (ISBS 2017)*, vol. 6, Cham: Springer International Publishing, 2018, pp. 102–113. DOI: 10.1007/978-3-319-63709-9{_}8.

[37] S. Lasvaux, G. Habert, B. Peuportier, and J. Chevalier, "Comparison of generic and product-specific Life Cycle Assessment databases: application to construction materials used in building LCA studies", *International Journal of Life Cycle Assessment*, vol. 20, no. 11, pp. 1473–1490, Nov. 2015. DOI: 10.1007/s11367-015-0938-z.

[38] C. Bueno, L. M. Pereira, and M. M. Fabricio, "Life cycle assessment and environmental-based choices at the early design stages: an application using building information modelling", *Architectural Engineering and Design Management*, vol. 14, no. 5, pp. 332–346, Sep. 2018. DOI: 10.1080/17452007.2018.1458593.

[39] A. Rønning and A. Brekke, "Life cycle assessment (LCA) of the building sector: Strengths and weaknesses", in *Eco-Efficient Construction and Building Materials: Life Cycle Assessment (LCA), Eco-Labelling and Case Studies*, Woodhead Publishing, Jan. 2013, pp. 63–83. DOI: 10.1533/9780857097729.1.63.

[40] R. Häggström, "Livscykelanalys inom byggbranschen: Kartläggning av kompetens- och intresseskillnader inom offentlig och privat sektor, samt verktygets framtid", Miljö- och hälsoskyddsprogrammet, Umeå, Tech. Rep., 2018. [Online]. Available: https://umu.diva-portal.org/smash/get/diva2:1223047/FULLTEXT01.pdf.

[41] Regeringskansliet, *Det klimatpolitiska ramverket*, 2017. [Online]. Available: https://www.regeringen.se/artiklar/2017/06/det-klimatpolitiska-ramverket/.

[42] J. Edgren, "Byggindustrin använder upp världens sandreserver", *Ny Teknik*, Oct. 2018. [Online]. Available: https://www.nyteknik.se/miljo/byggindustrin-anvander-upp-varldens-sandreserver-6937456.

[43] M. Larsson, M. Erlandsson, T. Malmqvist, and J. Kellner, "Byggandets klimatpåverkan: Livscykelberäkning av klimatpåverkan för ett nyproducerat flerbostadshus med massiv stomme av trä", IVL Svenska Miljöinstitutet, Stockholm, Tech. Rep., 2016. [Online]. Available: https://www.gsfacket.se/globalassets/darfor-ska-sverige-bygga-hus-i-tra/ivl-hela-studien.pdf.

[44] Joint Research Center, *Draft recommended LCIA methods*. Luxemburg: Publication Office of the European Union, 2011, ISBN: 9789279174513. DOI: 10.278/33030. [Online]. Available: http://lct.jrc.ec.europa.eu/.

[45] M. Goedkoop, M. Huijbregts, R. Heijungs, A. D. Schryver, J. Struijs, and R. van Zelm, "ReCiPe 2008 Characterisation", Netherlands, Tech. Rep., 2013.

[46] A. Olsson and S. Anel, "Defining a Reference Building according to LEED V4, to Enable Comparison of LCA Alternatives", Helsingborg, Tech. Rep., 2015. [Online]. Available: http://www.ebd.lth.se/fileadmin/energi_byggnadsdesign/publications/exjobb/15-6.pdf.

[47] Sweden Green Building Council, *Indikatorer i Miljöbyggnad*, 2019. [Online]. Available: https://www.sgbc.se/certifiering/miljobyggnad/certifiera-med-miljobyggnad/indikatorer-i-miljobyggnad/.

A

Appendix 1

Table A.1-A.24 presents the results in each impact category for all the building elements considered in the LCA.

Table A.1: *Results of the LCA of the ground construction, complementary, presented by impact per square meter heated floor area,* A_{Temp}

01. Ground Construction, Complementary		
Impact category	**Unit**	**Impact/$\mathbf{A}_{Temp}$**
Climate change	kg CO_2 eq	<1
Ozone depletion	kg CFC-11 eq	<0.001
Terrestrial acidification	kg SO_2 eq	<0.001
Freshwater eutrophication	kg P eq	<0.001
Marine eutrophication	kg N eq	<0.001
Human toxicity	kg 1,4-DB eq	<0.1
Photochemical oxidant formation	kg NMVOC	<0.001
Particulate matter formation	kg PM10 eq	<0.001
Terrestrial ecotoxicity	kg 1,4-DB eq	<0.001
Freshwater ecotoxicity	kg 1,4-DB eq	<0.01
Marine ecotoxicity	kg 1,4-DB eq	<0.01
Ionising radiation	kBq U235 eq	<0.01
Agricultural land occupation	m^2a	<0.1
Urban land occupation	m^2a	<0.01
Natural land transformation	m^2	<0.001
Water depletion	m^3	<1
Metal depletion	kg Fe eq	<1
Fossil depletion	kg oil eq	<0.1

Table A.2: *Results of the LCA of the ground construction presented by impact per square meter heated floor area, A_{Temp}*

02. Ground Construction		
Impact category	**Unit**	**Impact/A_{Temp}**
Climate change	kg CO_2 eq	27
Ozone depletion	kg CFC-11 eq	<0.001
Terrestrial acidification	kg SO_2 eq	<0.1
Freshwater eutrophication	kg P eq	<0.01
Marine eutrophication	kg N eq	<0.01
Human toxicity	kg 1,4-DB eq	8
Photochemical oxidant formation	kg NMVOC	<1
Particulate matter formation	kg PM10 eq	<0.1
Terrestrial ecotoxicity	kg 1,4-DB eq	<0.01
Freshwater ecotoxicity	kg 1,4-DB eq	<1
Marine ecotoxicity	kg 1,4-DB eq	<1
Ionising radiation	kBq U235 eq	2
Agricultural land occupation	m^2a	<1
Urban land occupation	m^2a	<1
Natural land transformation	m^2	<0.01
Water depletion	m^3	55
Metal depletion	kg Fe eq	11
Fossil depletion	kg oil eq	5

Table A.3: *Results of the LCA of the ground slab presented by impact per square meter heated floor area,* A_{Temp}

03. Ground Slab		
Impact category	**Unit**	**Impact/$\mathbf{A}_{Temp}$**
Climate change	kg CO_2 eq	74
Ozone depletion	kg CFC-11 eq	<0.001
Terrestrial acidification	kg SO_2 eq	<1
Freshwater eutrophication	kg P eq	<0.1
Marine eutrophication	kg N eq	<0.01
Human toxicity	kg 1,4-DB eq	21
Photochemical oxidant formation	kg NMVOC	<1
Particulate matter formation	kg PM10 eq	<1
Terrestrial ecotoxicity	kg 1,4-DB eq	<0.01
Freshwater ecotoxicity	kg 1,4-DB eq	<1
Marine ecotoxicity	kg 1,4-DB eq	<1
Ionising radiation	kBq U235 eq	5
Agricultural land occupation	m^2a	<1
Urban land occupation	m^2a	<1
Natural land transformation	m^2	<0.01
Water depletion	m^3	144
Metal depletion	kg Fe eq	26
Fossil depletion	kg oil eq	14

Table A.4: *Results of the LCA of the structural elements, walls, presented by impact per square meter heated floor area,* A_{Temp}

04. the Structural Elements, Walls		
Impact category	**Unit**	**Impact/A_{Temp}**
Climate change	kg CO_2 eq	13
Ozone depletion	kg CFC-11 eq	<0.001
Terrestrial acidification	kg SO_2 eq	<0.1
Freshwater eutrophication	kg P eq	<0.01
Marine eutrophication	kg N eq	<0.01
Human toxicity	kg 1,4-DB eq	4
Photochemical oxidant formation	kg NMVOC	<0.1
Particulate matter formation	kg PM10 eq	<0.1
Terrestrial ecotoxicity	kg 1,4-DB eq	<0.001
Freshwater ecotoxicity	kg 1,4-DB eq	<1
Marine ecotoxicity	kg 1,4-DB eq	<1
Ionising radiation	kBq U235 eq	<1
Agricultural land occupation	m^2a	<1
Urban land occupation	m^2a	<1
Natural land transformation	m^2	<0.001
Water depletion	m^3	28
Metal depletion	kg Fe eq	6
Fossil depletion	kg oil eq	2

Table A.5: *Results of the LCA of the prefabricated elements presented by impact per square meter heated floor area,* A_{Temp}

05. Prefabricated Elements		
Impact category	**Unit**	**Impact/$\mathbf{A}_{Temp}$**
Climate change	kg CO_2 eq	5
Ozone depletion	kg CFC-11 eq	<0.001
Terrestrial acidification	kg SO_2 eq	<0.1
Freshwater eutrophication	kg P eq	<0.001
Marine eutrophication	kg N eq	<0.001
Human toxicity	kg 1,4-DB eq	<1
Photochemical oxidant formation	kg NMVOC	<0.1
Particulate matter formation	kg PM10 eq	<0.01
Terrestrial ecotoxicity	kg 1,4-DB eq	<0.001
Freshwater ecotoxicity	kg 1,4-DB eq	<0.1
Marine ecotoxicity	kg 1,4-DB eq	<0.1
Ionising radiation	kBq U235 eq	<1
Agricultural land occupation	m^2a	<1
Urban land occupation	m^2a	<0.1
Natural land transformation	m^2	<0.001
Water depletion	m^3	6
Metal depletion	kg Fe eq	<1
Fossil depletion	kg oil eq	1

Table A.6: *Results of the LCA of the structural elements, beams, presented by impact per square meter heated floor area,* A_{Temp}

06. Structural Elements, Beams		
Impact category	**Unit**	**Impact/A_{Temp}**
Climate change	kg CO_2 eq	141
Ozone depletion	kg CFC-11 eq	<0.001
Terrestrial acidification	kg SO_2 eq	<1
Freshwater eutrophication	kg P eq	<0.1
Marine eutrophication	kg N eq	<0.1
Human toxicity	kg 1,4-DB eq	20
Photochemical oxidant formation	kg NMVOC	<1
Particulate matter formation	kg PM10 eq	<1
Terrestrial ecotoxicity	kg 1,4-DB eq	<0.01
Freshwater ecotoxicity	kg 1,4-DB eq	<1
Marine ecotoxicity	kg 1,4-DB eq	<1
Ionising radiation	kBq U235 eq	12
Agricultural land occupation	m^2a	1
Urban land occupation	m^2a	1
Natural land transformation	m^2	<0.1
Water depletion	m^3	193
Metal depletion	kg Fe eq	11
Fossil depletion	kg oil eq	19

Table A.7: *Results of the LCA of the steel work presented by impact per square meter heated floor area, A_{Temp}*

07. Steel Work		
Impact category	**Unit**	**Impact/A_{Temp}**
Climate change	kg CO_2 eq	3
Ozone depletion	kg CFC-11 eq	<0.001
Terrestrial acidification	kg SO_2 eq	<0.1
Freshwater eutrophication	kg P eq	<0.01
Marine eutrophication	kg N eq	<0.001
Human toxicity	kg 1,4-DB eq	3
Photochemical oxidant formation	kg NMVOC	<0.1
Particulate matter formation	kg PM10 eq	<0.01
Terrestrial ecotoxicity	kg 1,4-DB eq	<0.001
Freshwater ecotoxicity	kg 1,4-DB eq	<0.1
Marine ecotoxicity	kg 1,4-DB eq	<0.1
Ionising radiation	kBq U235 eq	<1
Agricultural land occupation	m^2a	<0.1
Urban land occupation	m^2a	<0.1
Natural land transformation	m^2	<0.001
Water depletion	m^3	16
Metal depletion	kg Fe eq	4
Fossil depletion	kg oil eq	<1

Table A.8: *Results of the LCA of the external roof presented by impact per square meter heated floor area, A_{Temp}*

08. External Roof		
Impact category	**Unit**	**Impact/A_{Temp}**
Climate change	kg CO_2 eq	11
Ozone depletion	kg CFC-11 eq	<0.001
Terrestrial acidification	kg SO_2 eq	<0.1
Freshwater eutrophication	kg P eq	<0.01
Marine eutrophication	kg N eq	<0.001
Human toxicity	kg 1,4-DB eq	4
Photochemical oxidant formation	kg NMVOC	<0.1
Particulate matter formation	kg PM10 eq	<0.1
Terrestrial ecotoxicity	kg 1,4-DB eq	<0.01
Freshwater ecotoxicity	kg 1,4-DB eq	<0.1
Marine ecotoxicity	kg 1,4-DB eq	<0.1
Ionising radiation	kBq U235 eq	2
Agricultural land occupation	m^2a	40
Urban land occupation	m^2a	<1
Natural land transformation	m^2	<0.01
Water depletion	m^3	23
Metal depletion	kg Fe eq	1
Fossil depletion	kg oil eq	4

Table A.9: *Results of the LCA of the external roof, complementary, presented by impact per square meter heated floor area,* A_{Temp}

09. External Roof, Complementary		
Impact category	**Unit**	**Impact/A_{Temp}**
Climate change	kg CO_2 eq	1
Ozone depletion	kg CFC-11 eq	<0.001
Terrestrial acidification	kg SO_2 eq	<0.1
Freshwater eutrophication	kg P eq	<0.001
Marine eutrophication	kg N eq	<0.001
Human toxicity	kg 1,4-DB eq	<1
Photochemical oxidant formation	kg NMVOC	<0.01
Particulate matter formation	kg PM10 eq	<0.01
Terrestrial ecotoxicity	kg 1,4-DB eq	<0.001
Freshwater ecotoxicity	kg 1,4-DB eq	<0.1
Marine ecotoxicity	kg 1,4-DB eq	<0.1
Ionising radiation	kBq U235 eq	<1
Agricultural land occupation	m^2a	4
Urban land occupation	m^2a	<0.1
Natural land transformation	m^2	<0.001
Water depletion	m^3	5
Metal depletion	kg Fe eq	<1
Fossil depletion	kg oil eq	<1

Table A.10: *Results of the LCA of the sheet metal presented by impact per square meter heated floor area, A_{Temp}*

10. Sheet Metal		
Impact category	**Unit**	**Impact/A_{Temp}**
Climate change	kg CO_2 eq	<1
Ozone depletion	kg CFC-11 eq	<0.001
Terrestrial acidification	kg SO_2 eq	<0.01
Freshwater eutrophication	kg P eq	<0.001
Marine eutrophication	kg N eq	<0.001
Human toxicity	kg 1,4-DB eq	2
Photochemical oxidant formation	kg NMVOC	<0.01
Particulate matter formation	kg PM10 eq	<0.01
Terrestrial ecotoxicity	kg 1,4-DB eq	<0.001
Freshwater ecotoxicity	kg 1,4-DB eq	<0.1
Marine ecotoxicity	kg 1,4-DB eq	<0.1
Ionising radiation	kBq U235 eq	<1
Agricultural land occupation	m^2a	<0.1
Urban land occupation	m^2a	<0.1
Natural land transformation	m^2	<0.001
Water depletion	m^3	3
Metal depletion	kg Fe eq	<0.1
Fossil depletion	kg oil eq	<1

Table A.11: *Results of the LCA of building complementary, steel, presented by impact per square meter heated floor area, A_{Temp}*

11. Building Complementary, Steel		
Impact category	**Unit**	**Impact/$\mathbf{A}_{Temp}$**
Climate change	kg CO_2 eq	4
Ozone depletion	kg CFC-11 eq	<0.001
Terrestrial acidification	kg SO_2 eq	<0.1
Freshwater eutrophication	kg P eq	<0.001
Marine eutrophication	kg N eq	<0.001
Human toxicity	kg 1,4-DB eq	2
Photochemical oxidant formation	kg NMVOC	<0.1
Particulate matter formation	kg PM10 eq	<0.01
Terrestrial ecotoxicity	kg 1,4-DB eq	<0.001
Freshwater ecotoxicity	kg 1,4-DB eq	<0.1
Marine ecotoxicity	kg 1,4-DB eq	<0.1
Ionising radiation	kBq U235 eq	<1
Agricultural land occupation	m^2a	2
Urban land occupation	m^2a	<0.1
Natural land transformation	m^2	<0.001
Water depletion	m^3	18
Metal depletion	kg Fe eq	2
Fossil depletion	kg oil eq	<1

Table A.12: *Results of the LCA of structural elements, complementary, presented by impact per square meter heated floor area, A_{Temp}*

12. Structural Elements, Complementary		
Impact category	**Unit**	**Impact/$\mathbf{A}_{Temp}$**
Climate change	kg CO_2 eq	4
Ozone depletion	kg CFC-11 eq	<0.001
Terrestrial acidification	kg SO_2 eq	<0.1
Freshwater eutrophication	kg P eq	<0.001
Marine eutrophication	kg N eq	<0.001
Human toxicity	kg 1,4-DB eq	2
Photochemical oxidant formation	kg NMVOC	<0.1
Particulate matter formation	kg PM10 eq	<0.01
Terrestrial ecotoxicity	kg 1,4-DB eq	<0.001
Freshwater ecotoxicity	kg 1,4-DB eq	<0.1
Marine ecotoxicity	kg 1,4-DB eq	<0.1
Ionising radiation	kBq U235 eq	<1
Agricultural land occupation	m^2a	3
Urban land occupation	m^2a	<0.1
Natural land transformation	m^2	<0.001
Water depletion	m^3	12
Metal depletion	kg Fe eq	2
Fossil depletion	kg oil eq	1

Table A.13: *Results of the LCA of windows and doors presented by impact per square meter heated floor area, A_{Temp}*

13. Windows and Doors		
Impact category	**Unit**	**Impact/$\mathbf{A}_{Temp}$**
Climate change	kg CO_2 eq	8
Ozone depletion	kg CFC-11 eq	<0.001
Terrestrial acidification	kg SO_2 eq	<0.1
Freshwater eutrophication	kg P eq	<0.01
Marine eutrophication	kg N eq	<0.01
Human toxicity	kg 1,4-DB eq	4
Photochemical oxidant formation	kg NMVOC	<0.1
Particulate matter formation	kg PM10 eq	<0.01
Terrestrial ecotoxicity	kg 1,4-DB eq	<0.001
Freshwater ecotoxicity	kg 1,4-DB eq	<1
Marine ecotoxicity	kg 1,4-DB eq	<1
Ionising radiation	kBq U235 eq	<1
Agricultural land occupation	m^2a	16
Urban land occupation	m^2a	<1
Natural land transformation	m^2	<0.01
Water depletion	m^3	23
Metal depletion	kg Fe eq	4
Fossil depletion	kg oil eq	2

Table A.14: *Results of the LCA of building complementary presented by impact per square meter heated floor area, A_{Temp}*

14. Building Complementary		
Impact category	**Unit**	**Impact/A_{Temp}**
Climate change	kg CO_2 eq	<1
Ozone depletion	kg CFC-11 eq	<0.001
Terrestrial acidification	kg SO_2 eq	<0.01
Freshwater eutrophication	kg P eq	<0.01
Marine eutrophication	kg N eq	<0.001
Human toxicity	kg 1,4-DB eq	<1
Photochemical oxidant formation	kg NMVOC	<0.01
Particulate matter formation	kg PM10 eq	<0.01
Terrestrial ecotoxicity	kg 1,4-DB eq	<0.001
Freshwater ecotoxicity	kg 1,4-DB eq	<0.1
Marine ecotoxicity	kg 1,4-DB eq	<0.1
Ionising radiation	kBq U235 eq	<0.1
Agricultural land occupation	m^2a	<0.1
Urban land occupation	m^2a	<0.1
Natural land transformation	m^2	<0.001
Water depletion	m^3	5
Metal depletion	kg Fe eq	1
Fossil depletion	kg oil eq	<1

Table A.15: *Results of the LCA of sub floor presented by impact per square meter heated floor area, A_{Temp}*

15. Sub Floor		
Impact category	**Unit**	**Impact/$\mathbf{A}_{Temp}$**
Climate change	kg CO_2 eq	10
Ozone depletion	kg CFC-11 eq	<0.001
Terrestrial acidification	kg SO_2 eq	<0.1
Freshwater eutrophication	kg P eq	<0.001
Marine eutrophication	kg N eq	<0.001
Human toxicity	kg 1,4-DB eq	1
Photochemical oxidant formation	kg NMVOC	<0.1
Particulate matter formation	kg PM10 eq	<0.1
Terrestrial ecotoxicity	kg 1,4-DB eq	<0.001
Freshwater ecotoxicity	kg 1,4-DB eq	<0.1
Marine ecotoxicity	kg 1,4-DB eq	<0.1
Ionising radiation	kBq U235 eq	<1
Agricultural land occupation	m^2a	<1
Urban land occupation	m^2a	<0.1
Natural land transformation	m^2	<0.001
Water depletion	m^3	13
Metal depletion	kg Fe eq	<1
Fossil depletion	kg oil eq	2

Table A.16: *Results of the LCA of internal walls presented by impact per square meter heated floor area, A_{Temp}*

16. Internal Walls		
Impact category	**Unit**	**Impact/$\mathbf{A}_{Temp}$**
Climate change	kg CO_2 eq	10
Ozone depletion	kg CFC-11 eq	<0.001
Terrestrial acidification	kg SO_2 eq	<0.1
Freshwater eutrophication	kg P eq	<0.01
Marine eutrophication	kg N eq	<0.01
Human toxicity	kg 1,4-DB eq	6
Photochemical oxidant formation	kg NMVOC	<0.1
Particulate matter formation	kg PM10 eq	<0.1
Terrestrial ecotoxicity	kg 1,4-DB eq	<0.01
Freshwater ecotoxicity	kg 1,4-DB eq	<1
Marine ecotoxicity	kg 1,4-DB eq	<1
Ionising radiation	kBq U235 eq	2
Agricultural land occupation	m^2a	10
Urban land occupation	m^2a	<1
Natural land transformation	m^2	<0.01
Water depletion	m^3	38
Metal depletion	kg Fe eq	6
Fossil depletion	kg oil eq	3

Table A.17: *Results of the LCA of internal roof presented by impact per square meter heated floor area,* A_{Temp}

17. Internal Roof		
Impact category	**Unit**	**Impact/A$_{Temp}$**
Climate change	kg CO_2 eq	3
Ozone depletion	kg CFC-11 eq	<0.001
Terrestrial acidification	kg SO_2 eq	<0.1
Freshwater eutrophication	kg P eq	<0.01
Marine eutrophication	kg N eq	<0.001
Human toxicity	kg 1,4-DB eq	2
Photochemical oxidant formation	kg NMVOC	<0.1
Particulate matter formation	kg PM10 eq	<0.1
Terrestrial ecotoxicity	kg 1,4-DB eq	<0.001
Freshwater ecotoxicity	kg 1,4-DB eq	<0.1
Marine ecotoxicity	kg 1,4-DB eq	<0.1
Ionising radiation	kBq U235 eq	<1
Agricultural land occupation	m^2a	<1
Urban land occupation	m^2a	<0.1
Natural land transformation	m^2	<0.001
Water depletion	m^3	15
Metal depletion	kg Fe eq	3
Fossil depletion	kg oil eq	<1

Table A.18: *Results of the LCA of internal doors and windows presented by impact per square meter heated floor area, A_{Temp}*

18. Internal Doors and Windows		
Impact category	**Unit**	**Impact/A_{Temp}**
Climate change	kg CO_2 eq	3
Ozone depletion	kg CFC-11 eq	<0.001
Terrestrial acidification	kg SO_2 eq	<0.1
Freshwater eutrophication	kg P eq	<0.01
Marine eutrophication	kg N eq	<0.001
Human toxicity	kg 1,4-DB eq	6
Photochemical oxidant formation	kg NMVOC	<0.1
Particulate matter formation	kg PM10 eq	<0.1
Terrestrial ecotoxicity	kg 1,4-DB eq	<0.001
Freshwater ecotoxicity	kg 1,4-DB eq	<1
Marine ecotoxicity	kg 1,4-DB eq	<1
Ionising radiation	kBq U235 eq	<1
Agricultural land occupation	m^2a	3
Urban land occupation	m^2a	<0.1
Natural land transformation	m^2	<0.001
Water depletion	m^3	14
Metal depletion	kg Fe eq	4
Fossil depletion	kg oil eq	<1

Table A.19: *Results of the LCA of internal stairs presented by impact per square meter heated floor area, A_{Temp}*

19. Internal Stairs		
Impact category	**Unit**	**Impact/A_{Temp}**
Climate change	kg CO_2 eq	<1
Ozone depletion	kg CFC-11 eq	<0.001
Terrestrial acidification	kg SO_2 eq	<0.001
Freshwater eutrophication	kg P eq	<0.001
Marine eutrophication	kg N eq	<0.001
Human toxicity	kg 1,4-DB eq	<0.1
Photochemical oxidant formation	kg NMVOC	<0.001
Particulate matter formation	kg PM10 eq	<0.001
Terrestrial ecotoxicity	kg 1,4-DB eq	<0.001
Freshwater ecotoxicity	kg 1,4-DB eq	<0.01
Marine ecotoxicity	kg 1,4-DB eq	<0.01
Ionising radiation	kBq U235 eq	<0.1
Agricultural land occupation	m^2a	<1
Urban land occupation	m^2a	<0.01
Natural land transformation	m^2	<0.001
Water depletion	m^3	<1
Metal depletion	kg Fe eq	<0.1
Fossil depletion	kg oil eq	<0.1

Table A.20: *Results of the LCA of surface layer, floor and stairs, presented by impact per square meter heated floor area, A_{Temp}*

20. Surface Layer, Floor and Stairs		
Impact category	**Unit**	**Impact/A_{Temp}**
Climate change	kg CO_2 eq	2
Ozone depletion	kg CFC-11 eq	<0.001
Terrestrial acidification	kg SO_2 eq	<0.1
Freshwater eutrophication	kg P eq	<0.001
Marine eutrophication	kg N eq	<0.001
Human toxicity	kg 1,4-DB eq	<1
Photochemical oxidant formation	kg NMVOC	<0.1
Particulate matter formation	kg PM10 eq	<0.01
Terrestrial ecotoxicity	kg 1,4-DB eq	<0.01
Freshwater ecotoxicity	kg 1,4-DB eq	<0.1
Marine ecotoxicity	kg 1,4-DB eq	<0.1
Ionising radiation	kBq U235 eq	<1
Agricultural land occupation	m^2a	25
Urban land occupation	m^2a	<1
Natural land transformation	m^2	<0.01
Water depletion	m^3	6
Metal depletion	kg Fe eq	<1
Fossil depletion	kg oil eq	<1

Table A.21: *Results of the LCA of surface layer, walls, presented by impact per square meter heated floor area, A_{Temp}*

21. Surface Layer, Walls		
Impact category	**Unit**	**Impact/A_{Temp}**
Climate change	kg CO_2 eq	1
Ozone depletion	kg CFC-11 eq	<0.001
Terrestrial acidification	kg SO_2 eq	<0.01
Freshwater eutrophication	kg P eq	<0.001
Marine eutrophication	kg N eq	<0.001
Human toxicity	kg 1,4-DB eq	<1
Photochemical oxidant formation	kg NMVOC	<0.01
Particulate matter formation	kg PM10 eq	<0.01
Terrestrial ecotoxicity	kg 1,4-DB eq	<0.001
Freshwater ecotoxicity	kg 1,4-DB eq	<0.1
Marine ecotoxicity	kg 1,4-DB eq	<0.1
Ionising radiation	kBq U235 eq	<1
Agricultural land occupation	m^2a	<0.1
Urban land occupation	m^2a	<0.1
Natural land transformation	m^2	<0.001
Water depletion	m^3	3
Metal depletion	kg Fe eq	<0.1
Fossil depletion	kg oil eq	<1

Table A.22: *Results of the LCA of surface layer, roof and false ceiling, presented by impact per square meter heated floor area, A_{Temp}*

22. Surface Layer, Roof and False Ceiling		
Impact category	**Unit**	**Impact/$\mathbf{A}_{Temp}$**
Climate change	kg CO_2 eq	<1
Ozone depletion	kg CFC-11 eq	<0.001
Terrestrial acidification	kg SO_2 eq	<0.01
Freshwater eutrophication	kg P eq	<0.001
Marine eutrophication	kg N eq	<0.001
Human toxicity	kg 1,4-DB eq	<1
Photochemical oxidant formation	kg NMVOC	<0.001
Particulate matter formation	kg PM10 eq	<0.001
Terrestrial ecotoxicity	kg 1,4-DB eq	<0.001
Freshwater ecotoxicity	kg 1,4-DB eq	<0.01
Marine ecotoxicity	kg 1,4-DB eq	<0.01
Ionising radiation	kBq U235 eq	<0.1
Agricultural land occupation	m^2a	<0.1
Urban land occupation	m^2a	<0.01
Natural land transformation	m^2	<0.001
Water depletion	m^3	1
Metal depletion	kg Fe eq	<0.1
Fossil depletion	kg oil eq	<1

Table A.23: *Results of the LCA of painting presented by impact per square meter heated floor area, A_{Temp}*

23. Painting		
Impact category	**Unit**	**Impact/A_{Temp}**
Climate change	kg CO_2 eq	1
Ozone depletion	kg CFC-11 eq	<0.001
Terrestrial acidification	kg SO_2 eq	<0.01
Freshwater eutrophication	kg P eq	<0.001
Marine eutrophication	kg N eq	<0.001
Human toxicity	kg 1,4-DB eq	<1
Photochemical oxidant formation	kg NMVOC	<0.01
Particulate matter formation	kg PM10 eq	<0.01
Terrestrial ecotoxicity	kg 1,4-DB eq	<0.001
Freshwater ecotoxicity	kg 1,4-DB eq	<0.1
Marine ecotoxicity	kg 1,4-DB eq	<0.1
Ionising radiation	kBq U235 eq	<0.1
Agricultural land occupation	m^2a	<0.1
Urban land occupation	m^2a	<0.01
Natural land transformation	m^2	<0.001
Water depletion	m^3	1
Metal depletion	kg Fe eq	<0.1
Fossil depletion	kg oil eq	<1

Table A.24: *Results of the LCA of transportation, elevators, presented by impact per square meter heated floor area,* A_{Temp}

24. Transporation, Elevators		
Impact category	**Unit**	**Impact/A$_{Temp}$**
Climate change	kg CO_2 eq	4
Ozone depletion	kg CFC-11 eq	<0.001
Terrestrial acidification	kg SO_2 eq	<0.1
Freshwater eutrophication	kg P eq	<0.01
Marine eutrophication	kg N eq	<0.001
Human toxicity	kg 1,4-DB eq	12
Photochemical oxidant formation	kg NMVOC	<0.1
Particulate matter formation	kg PM10 eq	<0.1
Terrestrial ecotoxicity	kg 1,4-DB eq	<0.001
Freshwater ecotoxicity	kg 1,4-DB eq	<1
Marine ecotoxicity	kg 1,4-DB eq	<1
Ionising radiation	kBq U235 eq	<1
Agricultural land occupation	m^2a	<1
Urban land occupation	m^2a	<0.1
Natural land transformation	m^2	<0.001
Water depletion	m^3	21
Metal depletion	kg Fe eq	5
Fossil depletion	kg oil eq	1