CHALMERS
UNIVERSITY OF TECHNOLOGY

Reducing the climate impact of a building in the design phase

Identifying focus areas in the design phase

Bachelor's thesis in Sustainable Environmental Engineering

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Department of Architecture and Civil Engineering, Building Technology
CHALMERS UNIVERSITY OF TECHNOLOGY
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Abstract

Some of the largest actors within the building sector have recently introduced road maps and goals to make the industry more sustainable. In order to establish a focus area for *sustainable building* development, this study looks to determine what elements and sections of a building contributes to the largest amount of *greenhouse gas emissions*. Additionally, the reader gets to follow an investigation into what possible measures and changes a *structural engineer* can make to reduce and improve the *climate impact* of the design of a building as well as what obstacles hinders the progress. The study has been made in collaboration with the building structures department at WSP Sweden in Gothenburg.

To sufficiently cover such a broad subject area, the study was carried out in three different sections. Firstly, a literature study was conducted on relevant papers, literature and industry standards. Additionally, research was also made into what sustainability goals have been set within the *building industry*.

Secondly, an interview study was conducted with stakeholders at the building structures department at WSP. The group of interviewees were chosen to be of differing positions, experience and insight into sustainable building technology to garner several perspectives and arguments. Additionally, a survey was sent out to the building structures department to accumulate a more quantitative result for certain matters.

The third and final section was a case study that was built upon the results of the interviews. The purpose of it was to visualise the amount of greenhouse gases that originate from the concrete in two separate hospital buildings, as well as the impact of the measures proposed in the interviews. The measures investigated were a reduction of *concrete* volume by reducing the thickness of all walls and slabs, lowering the concrete class of all concrete in the building and the impact of various amounts of *steel reinforcement* in the floor slabs.

The primary conclusion that can be drawn from this study is that there are large possibilities to reduce the greenhouse gas emissions of the building process, but the implementation is complex in the current industry climate. The case study demonstrates that the reduction of wall and slab thickness, as well as the lowering of concrete classes had a substantial impact on the buildings total greenhouse gas emissions. The majority of measures lifted in the interview study may also have a significant impact from a sustainable perspective, but often come with costs or risks in different aspects. Due to this, it is important to find optimum balance between different aspects, which is time-consuming. This has resulted in a great push for a more streamlined, user-friendly and restructured *design process* as it would help the industry to focus more on *optimization*. There is a strong consensus that this can change with further knowledge and experience of sustainable building technology.

Keywords: sustainable building, greenhouse gas, emissions, structural engineer, climate impact, building industry, concrete, steel reinforcement, design process, optimization

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John Boberg and Per Håkansson, Gothenburg, June 2020

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Abbreviations

3D	Three dimensional
BIM	Building information modeling
BIM-model	Building information model
BREEAM-SE	Building Research Establishment: Environmental Assessment Method - Sweden .
CO2	Carbon dioxide
CO2-eq	Carbon dioxide equivalents
DB	Design and build
DBB	Design-bid-build
EPD	Environmental Product Declaration
GHG	Greenhouse gas
GWP	Global warming potential
GC	Group Coordinator
HB1	Hospital Building 1
HB2	Hospital Building 2
IVA	Kungliga Ingenjörsvetenskapsakademien
LCA	Life cycle assessment
LEED	Leadership in Energy and Environmental Design
MC	Material Coordinator
SBI	Stålbyggnadsinstitutet
SC	Sustainability Coordinator
SE	Structural Engineer
SEMCo	Swedish Enviromental Management Council
SIS	Statens institutionsstyrelse
WELL	WELL Building Standard

1

Introduction

1.1 Background

The global warming of our planet has fueled discussion regarding how the impact of our society can be reduced, and a large emphasis has targeted the decisions of the individual. Choice of transport, type of diet and consumption habits have been debated a great deal. However, there has not been as large a focus on decisions made at work. The climate impact from building processes in Sweden is large, as it amounts to the emission of 10 million tons of greenhouse gases each year [1]. This corresponds to approximately 18,6 percentage of the total emissions of greenhouse gases in Sweden [2]. A large proportion of those emissions originate from the construction process of buildings, as major improvements have already been made to reduce the emission of greenhouse gases originating from the heating of houses [3]. This is largely attributed to a switch from fossil fuels to more environmental friendly options such as long-distance heating which led to a reduction by 86 percentage between 1990 and 2014 [4]. As there have previously not been any large focus to improve the construction processes, it is argued that the climate impact of such processes and the production of building materials is still significant.

Now, some of the biggest actors within the building sector of Sweden have introduced road maps with a mutual goal to make the industry more sustainable. The final objective of the road maps is to have net zero emissions of greenhouse gases by 2045. However, there are several obstacles and barriers to overcome before this is possible.

1.2 Purpose and Vision

The purpose of this thesis is to evaluate the possibilities to reduce the amount of emitted greenhouse gases from the manufacturing of buildings through optimization and educated decision making in the design process. Presently, complex software tools are used to perform LCA-analysis to investigate and review a buildings effect on the environment. Due to the complexity and uncertainty of the method, they are often only utilized by workers specializing in sustainable development [5]. These workers are often brought in late in the project, which means that they have little to no impact on the decisions in the design process as most decisions have already been made. Generally, the structure of a building amounts to the largest proportion of greenhouse gas emissions and a majority of the decisions made regarding the structure are made by structural engineers. The knowledge of workers specializing in sustainable development is therefor not taken into account when designing the structure of a building. Therefore, this report looks to establish what changes and improvements structural engineers can make in the design process of buildings to reduce the global warming potential of the construction. The report looks to localize where in a building the largest emissions originate and establish where there is potential to improve the optimization of a building design. Ideally, the result will be of assistance to structural engineers and guide them in their decision making to a reduction of greenhouse gas emissions and more optimized solutions and designs.

1.3 Method

This thesis will explore and highlight the different possibilities to optimize the building industry from a sustainable perspective and highlight those which seem most fruitful. The study was done in association with WSP, a company providing consultancy services within the building industry. More specifically, it was done in close collaboration with the building structures department at WSP in Gothenburg, specialising in structural design work. This allowed for constant input from structural engineers, currently active within the industry, throughout the study.

The first step was to collect information by doing a literature study followed by an in-depth interview study. This was then in turn complemented by a case study built upon the results of the previous studies. The literature study was carried out by gathering information of the subject in order to get a better insight of sustainable building related to the industry itself. In addition, trends and tendencies of the business in the building industry was identified and noted to confirm the interest in sustainable building. The second step was to conduct interviews with relevant people in the industry, in this case personnel at WSP, based on the results gathered in the literature study. The respondents were chosen so that they could display a wide picture of both the industry and the enterprise at the company.

The case study examined the different optimization measures produced from the results of the interviews and the literature study. These were compared and evaluated in terms global warming potential.

1.4 System boundaries

This study is made from an environmental standpoint and its purpose is to examine sustainability out of the same perspective. The study is made to examine the potential of different measures to reduce climate impact and then compare them to each other. Therefore, social and economic aspects are not taken into account. However, technical building requirements are taken into account through continuous input from structural engineers, but not studied in detail.

1.4.1 CO2-equivalents and Global Warming Potental, GWP

The function unit used for comparison is global warming potential GWP, as the study is made from an environmental perspective [6]. GWP is measured in carbon dioxide equivalents, CO2-equivalents, which is a metric used to measure an estimate of the global warming a specific greenhouse gas may cause. This is done by converting different greenhouse gases into the equivalent amount of carbon dioxide that gives cause to the same global warming potential as the original gas [7].

1.4.2 Production stages A1-A3

In the European standard for life cycle assessment, LCA, EN 15978:2011 [8], every phase of a buildings life cycle is covered. It includes every process from manufacturing, maintaining and everything until the end of it's lifespan. However, in this thesis the full life cycle is not considered. This is because other studies advocates that the early stages of an LCA of any building process have the largest amount of greenhouse gas emissions [9]. This can be observed in figure 1.1, which presents the results of an LCA performed on a building in Sweden. The boundaries are therefore set to the modules A1-A3, which tends to be referred to as cradle-to-gate or the full product stage. This includes every process from resource assessment to a final product, but not any processes after that.

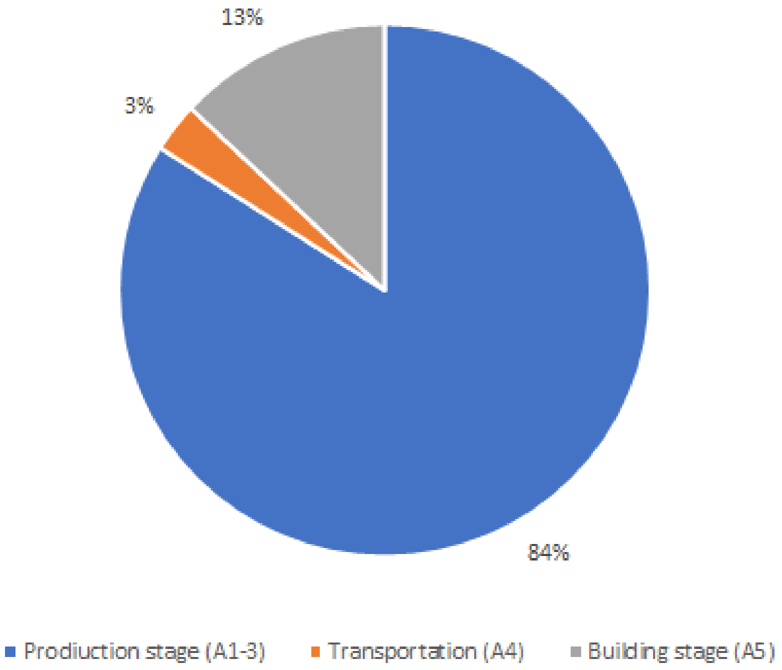


Figure 1.1: Emissions of greenhouse gases from the different stages in the building process of an apartment building in Sweden. [10]

1.4.3 Only frameworks made of concrete

As a building consists of multiple systems which could be separated into distinguishable categories, this thesis mainly focuses on the categories that emit the largest amounts of greenhouse gases. These include the framework, foundation and the climate shell and therefore the scope of this thesis have been floor slabs, walls, columns, ground slabs and pile caps in constructions. It is clear from previous studies that these account for the largest greenhouse gas emissions in the cradle-to-gate stage. [9] When it comes to material, this thesis will focus on concrete elements as they correspond to 50 percentage of greenhouse gas emissions. The steel reinforcement used in those elements will also be investigated. A chart over greenhouse gas emissions from a building in Sweden categorized by material is presented in figure 1.2.

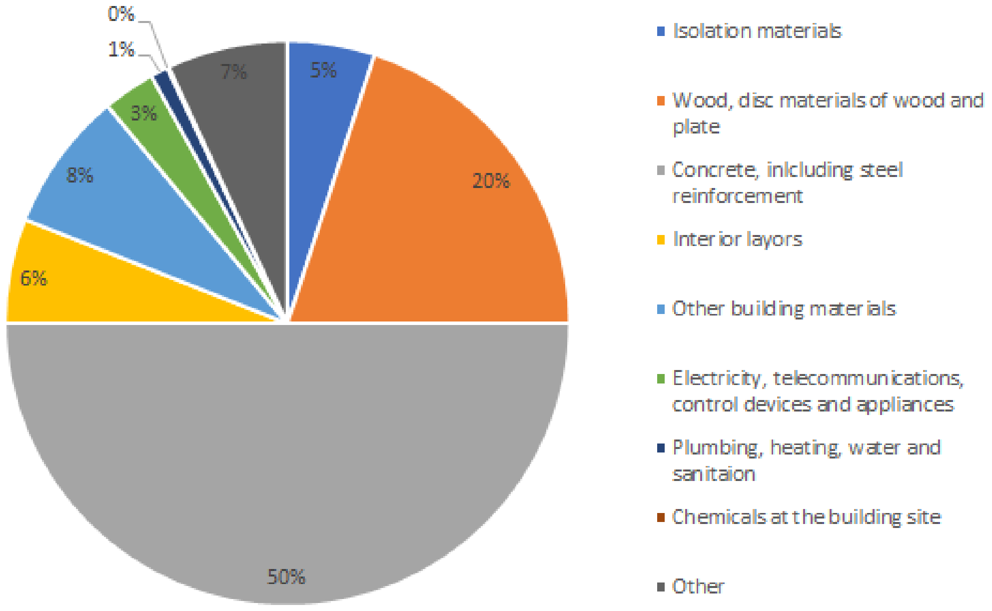


Figure 1.2: Emissions of greenhouse gases from the building materials in apartment buildings in Sweden. [11]

2

Theoretical Frame of Reference

2.1 The design process

This section presents the role of a structural engineer and the position he or she has in the design process. The information presented is brought forward from the structural engineers handbook [12] and input from the supervisors at the company, which means that parts of this section is specific for the building construction department at WSP in Gothenburg.

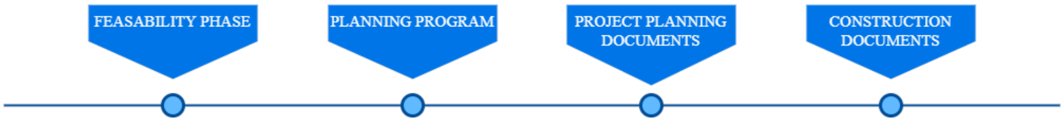


Figure 2.1: Workflow of the design process, seen from a structural engineers perspective [12].

2.1.1 Feasibility phase

Before starting the construction of a building a preliminary study must be made to get insight into how the project will develop over time. The study forms the basis for an eventual plan which consists of ruling conditions, the project possibilities, strategic design and description of the planned operation. Knowledge about possible challenges is collected and risks are identified at an early stage. A precise pilot can decrease unnecessary expenses due to complications and delays because of lack of knowledge. The aim of this phase is to draw the main features of a construction plan containing a roughly estimated time limit, distribute role of responsibility and outline the purpose of the project.

2.1.2 Planning program

This phase can be described as a form of investigation to gather information which then function as groundwork for everyone involved in the project. In the planning phase essential actions for the project are analyzed and decided. Different assignments are defined and distributed within the project and strategies are developed to locate and obtain supplies as well as plan the logistics. This phase is usually ongoing throughout the whole process, depending on the conditions and contract form. It is also the initial stage and examines and defines the conditions for the project and compose the basis for dictating various decisions in the design phase. It should involve an inventory of current circumstances and a description of the planned activity of the building. The information mentioned above is supported by requirements of a technical and environmental essence. This program also defines purpose, requirements, and properties and hence the framework for the project. The client has the sole responsibility for the building program. Many of the preconditions determined in this phase will affect the structural engineers work considerably.

2.1.3 Project planning documents

The project planning documents reports a definite coordinated formation of the buildings shape, function and construction. They also include a detailed plan of all the installations affecting the building, such as plumbing, electricity and ventilation systems. Size, location and design of these installations are also coordinated during this stage in the design process. The project planning documents are based from one of the alternatives presented in the propositions of the project but has room for adjustment and optimization of considerable variety. The documents shall state the construction of the framework, the stabilization system and how the foundation is designed. It should also include detailed descriptions of the dimensions of walls, columns, floors and other essential elements to the building. The shape and function of the climate shell should also be presented in these documents. The project planning documents is usually forged with such detail that they in some cases can be directly transcribed into construction documents ready for the building site.

2.1.4 Construction documents

The construction documents is a complete report of the buildings design, with definitive details about every aspect of the buildings functions. This implies that the scope, quality and execution of the project must be clearly stated. If necessary, descriptions of the design should supplement the drawings. Descriptions, documents linked to the project and drawings is usually presented according to Bygghandlingar 90 [13].

2.2 Life Cycle Assessment

2.2.1 Main Characteristics

LCA, short for Life Cycle Assessment, is a method to study the environmental impact of a product. It is often used in discussions concerning climate change and greenhouse gases, but usually covers a much broader range of environmental damages. Some issues that tend to be included are freshwater use, land occupation and transformation, aquatic eutrophication, toxic impacts on human health, depletion of non-renewable resources and eco-toxic effects from metals and synthetic organic chemicals [14]. The main reason for taking several environmental issues into account is to avoid so called “burden shifting”, which is what happens if efforts to reduce one type of issue unintentionally causes an increase of one or several other issues.

The purpose of conducting an LCA is to establish an apprehension of the size and what type of environmental impact, as well as what flows of resources exist during a life cycle. Each stage of the life cycle is investigated separately, which results in a clear perception of which stages are critical as well as what sort of environmental impact they cause. Such information allows for the identification of suitable measures required to ensure the life cycle has minimal environmental impact [14].

2.2.2 Life Cycle

Generally, all the processes required to deliver a product and it’s function are considered in an LCA [14]. As an example, the function of electricity can be to light a lamp. When this is the case the term “product system” is used, which implies that the perspective of the full life cycle is taken. A full life cycle does not only refer to the products lifespan, but also includes the processes taking place before and after that [14]. A physical products life-cycle begins with the harvesting and extraction of resources, which could for example be the planting and felling of a fir tree. This is followed up by the production processes, which could mean the fir tree gets turned into material used in the production of a building. This is in turn followed by the usage of the product, in this case referring to the intended usage of the building. The final step is the waste management of the product, which could mean that the material is reused in the end. Figure 2.2 show the different stages of a full life cycle, which are commonly used to set system boundaries in an LCA.

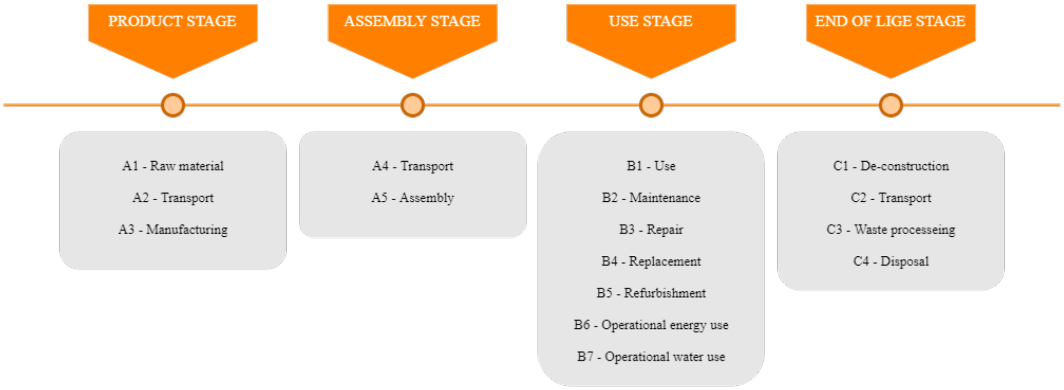


Figure 2.2: Stages of a full life cycle [15]

2.2.2.1 System Boundaries and Cradle-to-Gate

There are numerous different concepts of how to handle system boundaries in an LCA. One such concept is called cradle-to-gate. In contrast to considering the full life cycle, a cradle-to-gate study ends when the product leaves its manufacturing phase. In other words, the study ends when the product leaves the gates of the factory where it's being manufactured, hence the name cradle-to-gate [16]. In the example mentioned above, the study would end after the fir tree got turned into material for production use. All phases that happen before the manufacturing phase is still taken into account. The goal definition of the study and the intended use of the results determine whether or not a full life cycle perspective should be taken and what concept should be utilised [16]. In the case study of this thesis, the cradle-to-gate concept is applied as the study revolves around material use. Figure 2.3 shows the product stage and the phases that are taken into account in a cradle-to-gate study.

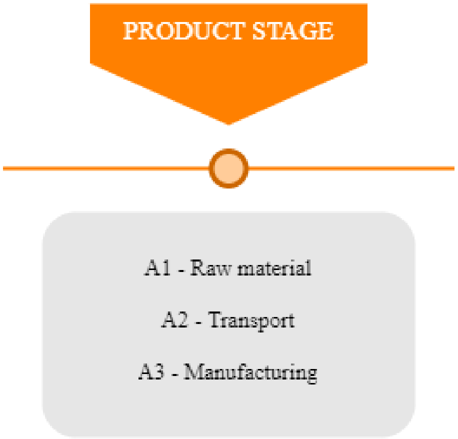


Figure 2.3: The product stage and the phases of a cradle-to-gate study [15]

2.2.3 Benefits of use

The main benefit of conducting an LCA is the possibility to identify environmentally devastating processes and avert burden shifting between different life cycle stages. It is also effective for identifying processes that materialize because of efforts to reduce the environmental impact in another process or life cycle stage, that unintentionally create environmental impacts in other processes or life cycle stages. These adverse processes may in some cases have worse environmental impacts than the original process. [14] An example of such is bio fuel, which is more environmentally friendly than fossil fuel at the use-stage, but is debated to have a worse impact in the harvest and extraction stage as it is a source of deforestation [14]. LCA is mainly used for product systems but can also be applied to more complex systems such as companies or energy management systems. The common feature through all types of LCA studies is that it focuses on the perspective of the function off the studied entity, and not just the entity itself. [14]

2.2.4 Scientific and Quantitative Nature

The purpose of an LCA is to find out how much the full life cycle of a product system impacts the environment. To effectively do that, the results of the LCA benefits from being quantified. If they are, it opens up the possibilities to judge which products or systems are better from an environmental perspective, or which processes within the system that has the largest contribution to the total environmental impact of the system [14].

This is commonly done by first mapping all the used resources and emissions, as well as their geographical location if possible. The potential environmental impact of said resources and emissions is then calculated by applying factors derived from mathematical cause/effect models. However, there is no general method how to perform the calculations in an LCA, but instead several different approaches exist. LCA calculations are very complex and therefore generally aim for the "best estimate", which means that average values are commonly used for the essential parameters [14].

The relationships between resource consumption or emissions and the environmental impact should be modelled based on proven causalities, for example a chemical reaction scheme or empirically observed relationships. [14] Additionally, value judgement is vital within an LCA, which strives to assign weight to different types of environmental issues. This is done to assist the evaluation of the overall environmental impact of a product system. These modelling choices can vary between projects, as perpetrators may make modelling choices based on the properties and scope of their own project, for example how many years into the future the assessment should be considered [14].

2.2.5 Strengths and Limitations

The main strength of LCA as a method is the comprehensiveness of the life cycle perspective and the broad coverage of environmental issues. It allows for comparisons of the environmental impact of large, complex systems made up of hundreds of different parameters with their origin in different geographical locations. However, the comprehensiveness is also a limitation, as the vast complexity demand simplifications and generalizations in the modelling of the assessment. On top of this, environmental impacts are generally aggregated with time and space, which means that emissions from today can have a larger impact in 20 years than they will have tomorrow. This hinders the calculation of actual environmental impacts using LCA. Therefore, a more accurate description of LCA results would therefore be potential environmental impact [14].

LCA follows the "best estimate" principle, which generally contributes to unbiased comparisons as the same amount of precaution is employed throughout the entire LCA. Though, it is also a limitation as the assessment in turn becomes based on average performances and values. As a result, following the "best estimate" principle means that risks of rare problematic events such as accidents at industrial sites, are not taken into consideration. To exemplify this, nuclear power appears very environmental friendly in LCA as the small risk of devastating disasters such as the ones at Chernobyl and Fukushima are not taken into account [14].

Additionally, an LCA cannot tell you if a product system is environmentally sustainable. It is solely able to tell you what is better for the environment and not if that option is environmentally sufficient [14].

2.2.6 EPD

The first approach to reduce the climate impact from the building industry is to locate the biggest source of emissions, according to the road map that Fossilfritt Sverige has produced [17]. By 2025 all companies within the industry should have localized and mapped their emissions of greenhouse gases. The method which will accomplish this in the Swedish building sector is LCA. As for now, the incorporation of LCA from an environmental perspective is still in its cradle but initiatives at companies is becoming more apparent with the industry's new objective in place. To establish this on an international level, environmental declarations has become key, as these set the standard for the potential impact from products produced in the industry. These environmental product declarations, EPDs (EN15804:2000), serves as information reports and contains the summary of the products character from an environmental aspect [18]. The implementation of EPDs are crucial to the road map that Fossilfritt Sveriges has produced.

The EPDs are categorized in three different type labels, from I to III, which serves as a grading system of credibility. The central difference between Type III and Type I and II, is third party eco logo labelling and self-declared environmental claim and the use of LCA methodology to quantify the climate impact of the product by third part. The system to implement EPDs to the building industry in Sweden is supported by the Swedish Environmental Management Council, SEMCo. As for today, the actors involved in the production stages in the Swedish building industry is in full motion to declare and label their assortment with EPDs. Furthermore, the Swedish building sector is also increasing it's involvement in environmental certification systems, the most common being BREEAAM-SE, Building Research Establishment, LEED and

Miljöbyggnad which are all environmental assessment methods adjusted for Swedish standards and conditions. These institutions certify new buildings performance from an environmental perspective [19]. The assessment of the certification is based on a range of different areas and then the buildings are scored and can be compared both nationally and internationally. The objective of these certifications is to create an industry which recognizes the importance of building climate friendly and encourage companies to be at the forefront when it comes to green initiatives in the sector, something that is in line with Fossilfritt Sverige's goals.

2.3 Driving forces and movements for sustainable construction

The biggest actors within the building sector have introduced road maps with a mutual goal to make the industry more sustainable. It is an initiative taken from Fossilfritt Sverige together with several large companies, such as WSP, NCC and SKANSKA [17]. The essence of the road map is to readjust the entire value chain of the building industry to eliminate all net emissions of greenhouse gases until 2045. This vision is fully in line with the values that Sweden has set for future challenges, which is to be climate neutral in 2045 while still being competitive. The road maps description of possibilities and obstacles to achieve net zero emissions within 25 year is summarized as an obstacle analysis. There are a lot of initiatives from different actors in the value chain but there are many challenges and readjustments to be made in the industry. The re-conversion of the sector infers that all the contributing parts in the value chain must adapt and undertake measures to improve. This means that everything must be optimized or rebuilt to overcome the problems at hand.

The timeline to secure a climate neutral value chain within the construction sector is:

2045: Net zero emissions of greenhouse gases.

2030: Reduce greenhouse gases with 75 percent (compared to 2015)

2025: The emissions of greenhouse gas are clearly reduced

2020-2025: Actors in the construction sector have localized and mapped their emissions and set goals to reduce them.

2.4 Obstacle analysis

2.4.1 Organizational barriers

The building sector mainly consists of temporary client organizations in which the construction projects has several independent actors. As for any project, the communication between the different actors is vital. Considering that the different actors are made up by several companies in disconnected departments the logistics is bound to pose obstacles. When communication is crippled throughout the organization, so is the information flow and knowledge shared between the different actors. These kinds of projects often hinder innovations and experience made in one part of the organization to spread to other parts of the organization [20]. The outcome of this being that innovation made in early stages and by the manufacturer tend to stay unheard of and thus undeveloped. By extension, this may mean that the customer's ability to take advantage of innovative techniques within the supply chain is not utilized and these techniques are not implemented to the extent that would be possible in an organization with better structures for information flow.

This affects every aspect of the building industry, not the least conversion to a more climate friendly attitude. The lack of information flow between builder and product manufacturer in the industry results in that the manufacturer of a product has more knowledge than the buyer has. This makes it difficult for a builder to order less climate-impacting buildings and building materials, since it is difficult to determine without significant costs which building methods and materials results in lower climate impact from a life-cycle perspective [21].

2.4.2 No economic incentive

Another obstacle is that until this day there has not been any business advantage to approach more climate friendly methods of building. A buildings carbon footprint has not been and are still not today a crucial selling point in the industry. The economic incentive is weak for clients to order buildings with less GWP emissions, and at the same time there are no economic arguments for contractors to suggest more environmentally friendly materials or building methods.

When decisions are determined regarding when to apply innovative techniques in the building industry there are at least two factors that affect the substrate of the decision. The innovative techniques mainly concern the choice of material or the method of building. Usually the amount of information regarding the established and the new is not evenly balanced, to the advantage of the established. When it comes to material there is often more climate friendly options, but the demand is usually low, the reason being lack of knowledge about properties and a higher price. Not only does the material cost less because of a less established production process but there is an additional cost to build a proper base of how to implement the product, both in terms of time and money. This results in that the new product, with less information, is perceived as more insecure and is therefore less likely to be chosen instead of the more established method or material. And furthermore, even if the product is potentially more cost efficient is often opted out because the risk it is perceived to be higher.

3

Interviews

The purpose of the interviews was to create an overall view of the whole design process at the building structures department at WSP and extract information about the workflow as well as different chores for different positions. In total six interviews were held with eight different employees with various roles at the company. The employees can be categorized into four types of functions, which are structural engineer (SE), material expert (ME), group manager (GM) and sustainability coordinator (SC). It should be distinguished that the responses and opinions of the respondents are of their own opinions and do not reflect on their companies' values. It is also noteworthy that the interviews have been interpreted by the authors of this report and reproduced.

3.1 Method of the interviews

The interviews were fashioned in to a more qualitative matter to get further insight of the subject in addition to the results of the literature study [22]. They had a semi-structured build, which means that the interview had a set of questions determined in advanced with the freedom to peruse and follow up on specific subjects [23]. This also allowed for more open-end questions and the possibility to explore more optimization measures which had been overlooked in the literature study. As there was opportunity to contact the respondents subsequently, the interviews have been supplemented gradually with additional information. As different respondents had different positions within the company the questions were reformulated for each interview, but all were of the same essence.

- Why do you think buildings are not optimized from a sustainable perspective, even though it results in less global warming potential?
- Do you see any clear improvement opportunities within the company's design work in relation to sustainable development and climate impact?
- Where and what in the building has the largest potential for improvement?

In addition to the interviews a survey was sent out to the structural engineers at the building structures department at WSP. The survey was anonymous and the purpose of it was to get an idea of the decisions a structural engineer face on a daily basis, as well as the reasoning behind the decisions made [24]. In total there were

19, all of which were structural engineers of some sort, respondents to the survey. The results can be found in appendix C.

3.2 The respondents of the interviews

3.2.1 Interview with group manager

The GM has worked within the company in his current position for five years. Before that he has worked as a structural engineer and assignment coordinator in several companies. Therefore, he also has a lot of experience with calculations and a wide perspective of the design process. The daily tasks mostly consist of consulting employees regarding technical issues, but he also has a few projects of his own specializing in concrete reparation. It is safe to say that the group manager has a lot of experience within his field.

3.2.2 Interview with material experts at the company

The material experts at the company were stationed in differing locations in Sweden and they all had different areas of expertise. The material experts were interviewed simultaneously as separate interviews were not possible due to a lack of time from their end. Though, the unified constellation opened up discussions between the experts which resulted in a productive interview.

3.2.2.1 Material expert 1

ME1 is a civil engineer with over 25 years of experience from the building industry as a structural engineer. He has worked with foundations and structure in both steel and concrete constructions. He specializes in building technology and material options in joint constructions of steel and concrete as well as damage investigations on concrete constructions. ME1 is a certified designer within steel construction by SBI and Nordcert and acts as expert council within the same field at WSP.

3.2.2.2 Material expert 2

ME2 has experience as a projector, statistician and commission manager of offices, industrial premises, industries, and housing. He has worked with several projects with different kinds of structures with most types of materials. He has been involved with both modeling and production of manufacturing drawings for steel projects and prefabricated concrete. ME2 performs static calculations for foundations, steel, concrete, masonry, and wood structures as well as frame stability. ME2 is directly related to carries out construction and project management of construction, plumbing and electrical work etc, as well as holds permission for both BAS-P and BAS-U. He also conducts contract inspections. ME2 performs work as a moisture expert in both the design and production stages.

3.2.2.3 Material expert 3

ME3 was hired as a designer at WSP building design in Luleå from January 2007. Since the employment at WSP, the work has included rebuilding and new housing construction, smaller industrial production and participation in large industrial projects. ME3 is a member of the Concrete Coordinator of the Business Area's Technology Council, and is also a representative of the SIS Technical Committee for the revision of Eurocode 2 (TK556). ME3 is responsible for internal concrete training regarding preparation of regulations and conditions. Prior to WSP, he worked as a doctoral student at Luleå University of Technology with research in the reinforcement and repair of concrete structures.

3.2.3 Interview with sustainability coordinator

The SC has a Master of Science in sustainable development and over 6 years of experience working in her current position. She has worked within WSP in her current position for over four years and before that she worked at a similar position within another company for two additional years. Prior to taking the role as a sustainability coordinator, she still worked with similar questions and challenges and therefore has a total experience of over 11 years within the field of sustainability and environmental questions.

The purpose of her department is to minimize the environmental impact of projects, mainly through the optimization of resource- and energy usage. Her current role is to perform life cycles assessments of buildings that has been designed by the company. She generally enters projects at a later stage, as most of the building design needs to be determined to perform a life cycle assessment. Therefore, she normally has no bearing on decisions that may impact the environmental impact of the project. She is also specialized in several different environmental certificates such as LEED, WELL and Miljöbyggnad and has also worked as a sustainability mentor for employees in the directorate of the company. She also makes it clear that she has the perspective of sustainability and is not very proficient in the economic or social aspect perspective. Because of this, her answers are not to be treated with those aspects taken into account

3.3 Analysis of interviews

The interviews were analyzed in different steps. Each interview was either recorded or transcribed on a computer during the interview. Afterwards, they were proofread, restructured to some extent and sometimes supplemented by the respondents in subsequently. After all the interviews were conducted the content were analyzed and compared with studies from the literature study. Sometimes respondents gave answers that did not match any questions. In these cases, a decision was made whether the answers were relevant or not. Often, if two or more respondents gave a similar answer and it was somehow connected to the research question, it was of value for the study. The summary was then used in the creation of the results, which gave a clear view about the respondents' thoughts and experiences.

3.4 Result of interviews

The respondents gave a thorough and broad description of the design process of a building, with range from several different perspectives. Even though the respondents had different backgrounds and positions in the company all agreed that there are huge improvements to be made for the building industry to become more environmentally sustainable. Many of the respondents also agreed on where to begin the process for the company to become more environmentally friendly. Most of the respondents agreed that concrete is the material that accounts for the largest emissions which is confirming what was established in the literature study. Furthermore, it was also confirmed that this study should focus on the structures and climate shell of the constructions as they stand for the biggest quantities of concrete. Figure 3.1 shows a summary of the proposed measures by the interviewees of what can be done to reduce the climate impact of the building industry.

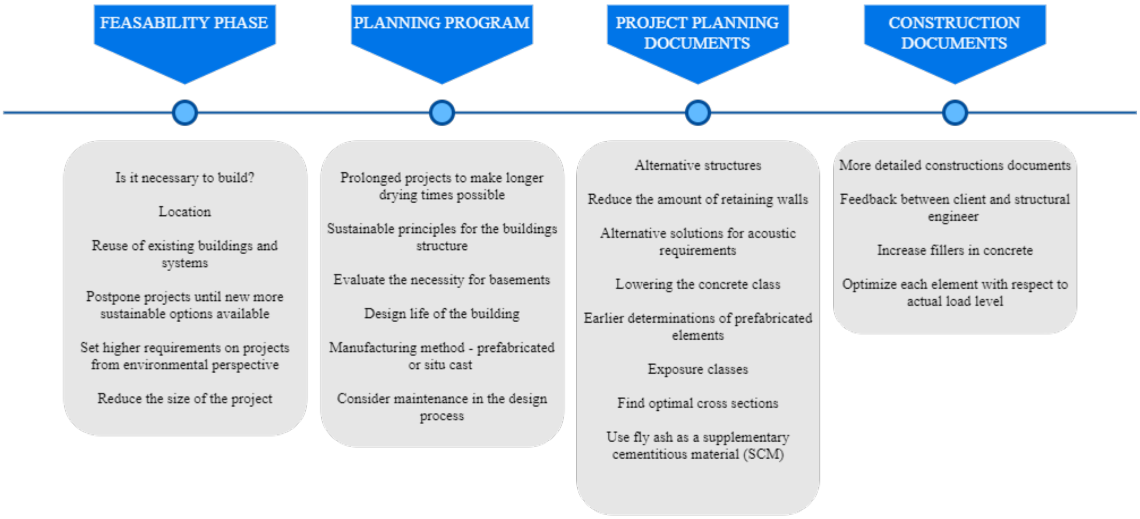


Figure 3.1: Summary of optimization measurements categorized by stages of workflow

3.4.1 Feasibility study

In the first stage of the design process of the building the structural engineers are not as involved as in the following stages. However, the interview with the sustainability coordinator who had in depth knowledge of LCA and sustainability in general came with suggestion from a broader perspective. It is also established in previous studies that the biggest effect on minimizing the environmental impact is made in the early stages in the design process [25]. The information provided from the sustainability coordinator at these stages should therefore be taken into consideration.

Is it necessary to build

The first item that was elevated from the sustainability coordinator was if it was necessary to build or manufacture at all. This is of course the most effective way of reducing and even eliminating emissions but is often not feasible as there is a demand for new buildings.

Location

The location of the building can have a great influence on the climate impact when analyzed from an LCA perspective. Topology decides the groundwork for the foundation and also the building itself and the design play a considerable role when minimizing the climate impact. The distance to the manufacture of materials should also be considered as transportation of the material contributes to the greenhouse gas emissions of the building in the production stage.

Reuse of existing buildings and systems

Instead of producing new buildings one should investigate the possibility to reuse or integrate existing constructions to new projects according to the group manager. This is one the foundations of the design process when looking at it from a LCA perspective. This item was later raised with the material experts which raised a discussion. ME1 elevated that it is not necessarily better to preserve older buildings as they are usually less efficient than newer productions.

Postpone projects until new more sustainable options are available

New, innovative options to produce buildings are constantly being developed. Some projects may be postponed waiting for new, more sustainable alternatives to be present.

Set higher requirements on projects from an environmental perspective

Another item that was elevated was the effect of higher requirements on projects from an environmental perspective. The respondents, independent of employment, all highlighted this item. It was not agreed upon from whom this initiative should come from. The group manager thought the client should take more responsibility for sustainable initiatives, which also the sustainability coordinator agreed upon.

Reduce the size of the project

One obvious measure to reduce greenhouse gas emissions is to basically make the buildings smaller. Smaller floors spans equal less amount of concrete used.

3.4.2 Planning program

In the planning program the principles of the project are evaluated and decided. As it is still in the early stages of the design process huge differences can be made from a sustainable perspective. As for the structural engineer's role in the process, he or she has more influence over the design plans and has some authority to propose alternatives that could be beneficial when trying to reduce the emissions of the projects.

Prolonged projects to make longer drying times possible

A subject that was raised from the material experts was that short construction times is a determining factor when choosing the concrete class in floors and walls. Shorter construction times usually equals higher concrete classes to meet the time requirements of the projects. Higher concrete classes have a higher amount of cement and is therefore more likely to contribute to a larger amount of greenhouse gases emitted from buildings. This was an item that the group manager also stressed.

Sustainable principles for the buildings structure

Structures made from concrete represent one of the biggest factors when it comes to climate impact. By using alternative structures such as ones made from steel or wood or a combination of those together with concrete can potentially reduce the greenhouse gases generated by the building. This was something that the sustainability coordinator stressed. However, both the material experts and the group manager underlined that concrete is a very convenient material to build with from an acoustic and fire safety perspective.

Evaluate the necessity for basements

As wall elements that are located in the basements usually are thicker and have a higher exposure class these cause a higher production of greenhouse gases according to the group managers. If these could be made thinner or even eliminated completely by simply not building a basement, there is a potential for huge greenhouse gas reductions. However, as the material experts pointed out the basement contributes to the buildings stability, which can in some cases be necessary for the construction.

Design life of the building

When making an LCA a buildings total life span is considered, from cradle to lifespan. The greenhouse gas emission from the production stage is divided over the building's life span. From an LCA perspective it could be beneficial if the building is built to endure a longer life and maintain a reasonable amount of greenhouse gas emissions in the production stages. This is an item both the group manager and material experts stressed.

Manufacturing method - prefabricated or situ cast

The material experts elevated that the focus should begin on the in-situ concrete. This is, according to them, because in most cases the prefabricated concrete is already optimized for its purpose.

Consider maintenance in the design process

A building is designed to last for a long time, to long for some of the material to endure without maintenance. When designing the building, emissions of material production should be weighed against emissions of material maintenance during its lifetime.

3.4.3 Project planning documents

It is in this stage where most of the respondents thought that the optimization should be initiated. The production of the project planning documents is where the structural engineers have the most influence and thus the best opportunity to initiate measures. The optimization measures might not have the same potential as the ones established in the early stages in the project as the structures of the project is already determined but there are still room for improvements.

Alternative structures

Just as in the planning program it is still relevant in the project planning documents to evaluate if the structure for the building is the best fit from a sustainable perspective. Material could still be changed to reduce the emissions of greenhouse gases. The build and function of the structure could also be evaluated for potential reduction of greenhouse gas emissions.

Reduce the amount of retaining walls

Retaining walls, usually located in the basement of a building, is a potential source for reduction for greenhouse gas emissions. If a basement is necessary, these should be optimized from a sustainable perspective at greater extent than regular walls according the group manager. These contains a higher concrete class and are usually thicker.

Lowering of the concrete class

The group manager elevated that the concrete classes are at this stage in the design process often over dimensioned for certain elements and later overlooked. This results in a higher concrete class than necessary. Concrete classes of higher quality have a higher concentration of cement which cause higher emissions of greenhouse gases. The material experts confirm this.

Alternative solutions for acoustic requirements

It is established that concrete is a huge contributor to a building's emissions of greenhouse gases. In many cases it is the acoustic requirements that is the design factor and sets the thickness of the elements. The sustainability coordinator proposes the possibility to reduce the thickness of the concrete and replace with another material with the same acoustic properties but with less climate impact.

Earlier determination of prefabricated elements

The material experts recommend the use of prefabricated elements instead of in situ cast elements when building concrete constructions. These are optimized to a greater extent than any in situ cast concrete and therefor better suited when building sustainable.

Exposure classes

Another item that was elevated in the interviews was how the requirements of the concrete of different elements could be reduced, especially when it comes to exposure class. Higher exposure classes result in higher concrete classes which cause more greenhouse gas emissions when reduced. These specially refers to wall elements which is exposed for weather and are located in the basements.

Increase the amount of steel reinforcement in cross section

By increasing the amount of steel reinforcement the load capacity could be increased, especially in floors. This is, of course, with the assumption that the steel is produced in a sustainable way.

Use fly ash as a supplementary cementitious material (SCM)

The use of fly ash as a binder in the concrete could also be a potential measure to reduce the emissions of greenhouse gases. There is much debate if fly ash would be a better supplement to cement, the argument being that fly ash is a byproduct from a industry that is primarily based on fossil fuels. It is also elevated from the material experts that the properties of concrete with fly ash as a binder is not fully tested and may differ from regular concrete.

3.4.4 Construction documents

The construction documents originate from the project planning documents. The structural engineer's role in this stage is limited when it comes to optimizations measures. However, there is improvements to be made in terms of evaluation which indirectly could be beneficial from an environmental sustainable standpoint.

More detailed constructions documents

More precise construction documents could reduce the amount of construction errors at the building sites. Mistakes in the design phase can easily be adjusted or fixed, but when errors or mistakes happen in the construction stages of a building, it usually results in higher emissions of greenhouse gases. More detailed constructions documents also results in more precise quantity take-offs and the risk inaccurate orders are reduced.

Feedback between client and contractor

A prolonged and a more in-depth dialog between the client and contractor could result in a greater chance to localize and examine different problems more efficiently. According to the sustainability coordinator this could improve the method to optimize a building from a sustainable perspective.

Increase fillers in concrete

Cement is the biggest contributing factor for greenhouse gas emissions in concrete. The production of the cement requires high temperatures and the refining of limestone emits greenhouse gases itself. By decreasing the amount of cement in the concrete and adding more filler it is possible to reduce the emissions of greenhouse gases, even if the thickness of walls is increased.

Optimize each element with respect to actual load level

As the building gets higher the load that the supporting columns and walls must carry is reduced. This is not always considered or overlooked to simplify the design of the construction. If the cross-section of the walls and columns would decrease with respect to load level it could have a considerable impact on the building's emissions of greenhouse gases.

3.5 Conclusion of the interviews

The general impression of all the respondents is that the reduction or manipulation of concrete is key when it comes to making a building more environmentally sustainable and that concrete measures should be implemented first. The measures that involves modifying the concrete in some way usually have a strong connection to a structural engineer's job role, and thus amount to big possibilities to optimize. Figure 3.2 lists the measures that the respondents wanted to investigate more thoroughly. Reducing the amount of concrete includes all the measures that in some way optimize the dimensions of the cross sections of concrete elements

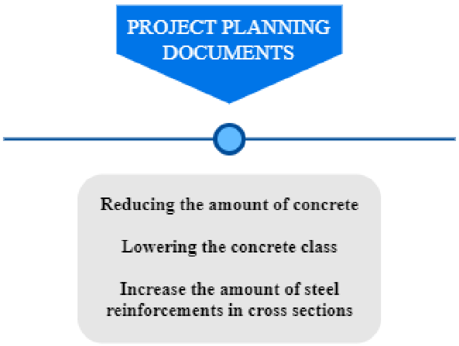


Figure 3.2: The chosen measures that are investigated in the case study. .

Other measures, especially those resulting in prolonged drying times as a consequence, is also hard to implement in today's financial climate. Prolonged building projects is from an economical perspective not arguable with clients according to the group manager and material experts. They indicate that the estimated times for a project is very hard to change, as longer building times are more expensive. The sustainability coordinator adds that measures that requires prolonged building time are more easily enforced in very early stages in a project.

3.6 Basis for case study

The interviews gave some implication of which optimization measures could be relevant or not. However, certain measures were considered very challenging implement in today's industry climate, but could be possible to apply in the future. Other measures lay outside of the field of work for the structural engineers at WSP. Some measures were not reasonable to implement because they were too time consuming. As the group manager stressed the structural engineer is under constant pressure from the client in terms of time. He also emphasized that it is not financially sustainable to increase the work hours to optimize buildings from a sustainable perspective at this time. However, as the demand for more sustainable alternatives increases from the clients so will the priorities of the structural designers. The sustainability coordinator agrees with this but adds that the measures should therefore be quick to implement, highly integrated into the structural engineer's workflow and easy to use, as they otherwise run the risk of being overlooked in a stressed work environment. All of the interviewees agreed that it is best to implement this in steps, one at a time. This lay the basis for the case study, where the measures that were deemed most feasible and at the same time effective are investigated more thoroughly.

4

Case study

The purpose of the case study was to visualize the results of the interview study as well as form an understanding of the total emissions from a specific building. In the interviews several possible measures to reduce the emission of greenhouse gases were proposed. However, none of them had been tested nor could any conclusions be drawn from former projects as there are no records of the measures been implemented previously. The intention of this case study was to test the measures in theory as well as compare them between two different buildings of similar character but with differing characteristics and functions. It was done from a sustainability perspective and aspects such as social or economic was not taken into account. Structural and technical requirements were not studied in detail, but input from structural engineers was continuously acquired during the process.

4.1 Method

As was established in the previous parts of this study, concrete is the largest contributor to greenhouse gas emissions in the construction process. To develop a better understanding of the size of this contribution, a case study was performed on construction projects developed by WSP. As the structural department at WSP regularly work with designing hospital buildings, it was deemed appropriate and relevant to study such projects. To be able to make comparisons and possibly find connections between different types of hospital constructions, the case study involved two different hospital projects of dissimilar character. These will be referred to as HB1 and HB2, short for Hospital Building 1 and Hospital Building 2.

The chosen measures that were investigated in the case study:

1. Reducing the thickness of walls and floor slabs by 50mm
2. Lowering the concrete class
    (a) C40/50 → C30/37
    (b) C30/37 → C25/30
3. Find optimal cross sections of steel reinforcement

The case study was performed by analyzing the structural BIM-models of the buildings. Its purpose was not to find the realistic and true values of emitted greenhouse gases from the two hospital buildings. Instead, it was to find representative values for the buildings that could be used to visualize the total emissions of greenhouse gases, to compare the buildings to each other as well as to compare the impact of different optimization measures to one another. While the aim still was to establish values as close to reality as possible, the usage of BIM-models brings a result that cannot be guaranteed to match the actual building. Therefore, the results of this case study need to be regarded as theoretical estimates.

As the purpose of the case study was to be able to calculate the amount of greenhouse gas emission from the concrete in the buildings, all other materials were excluded. The concrete in the model was compiled into volume data and exported to allow for further computing of emitted greenhouse gases. The data was then separated and categorized by building elements and its properties (regular floor structure, hollow core slabs, ground slab, backfilled and regular walls, columns, pile caps). The categorization varied between the two buildings as they were designed for differing purposes.

4.1.1 Basis for calculation of greenhouse gases

The amount of emitted greenhouse gases largely depend on the type of concrete class which led to calculations being done with five different classes (C25/30, C30/37, C35/45, C40/50, C50/60) to allow for comparisons between them. The values of emitted greenhouse gases to be used for the comparison were gathered from the EcoInvent database [26], which represents the LCA stages A1-A3. These values are presented in Table 4.1.

Concrete Class	C25/30	C30/37	C35/45	C40/50	C50/60
Greenhouse Gas Emissions [kg CO2-eq / m3]	231,34	314,51	325,54	326,4	355,64

Table 4.1: Greenhouse gas emissions per cubic meter concrete

However, these measurements did not include any GWP value for the concrete class C40/50. This class was estimated through interpolating, by plotting the values for C25/30, C30/37, C35/45 and C50/60 and adding a trendline between the plotted values. The x-axis was valued after the first number in the concrete class name, which represents the compressive strength the concrete can handle in cylindrical form. The y-axis represents the emitted greenhouse gases per cubic meter concrete. The plotted values were then used to calculate an estimation of the emitted C02-equivalents of C40/50, see Figure 4.1.

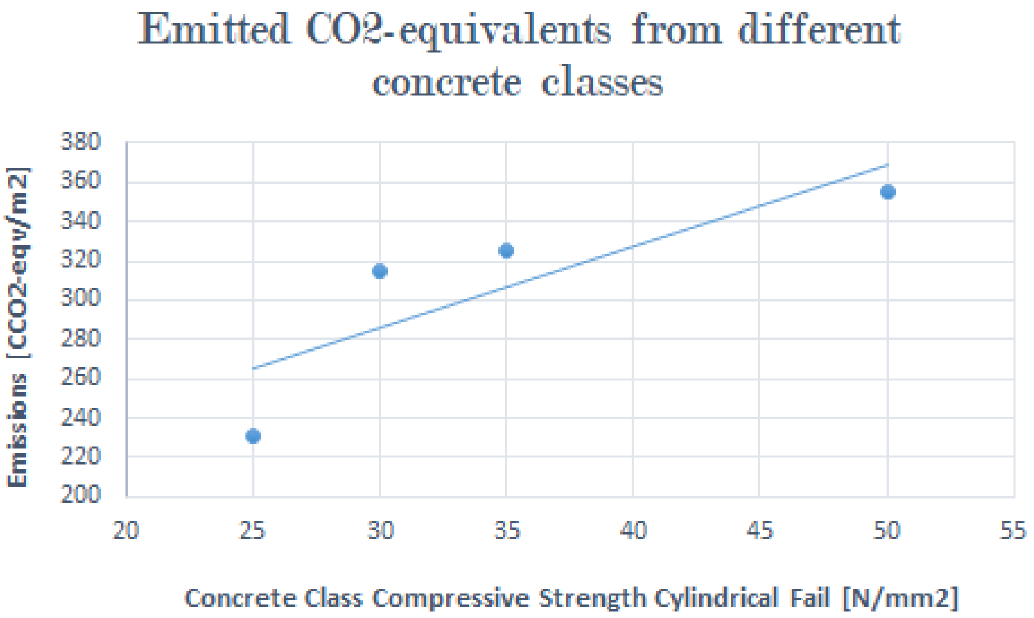


Figure 4.1: Plot of the GWP values of C25/30, C30/37, C35/45, C50/60 and an added trendline to estimate the GWP value of C40/50.

All calculations of emitted greenhouse gases were made in the same manner, by multiplying the concrete volume by the GWP gathered from the EPDs. The model for HB2 lacked information regarding what concrete class was used, and therefore an assumption that all the concrete was of the same class had to be made.

4.1.2 Impact of improved optimization of concrete

Several improvements to optimize the usage of concrete were gathered in the interviews and literature study, which would consequently reduce the emission of greenhouse gases. To find representative numbers describing the impact of the proposed improvements that was gathered from the interviews and literature, certain additional calculations and adjustments to the model were made.

4.1.2.1 Reducing the amount of concrete

To represent a reduction in the amount of concrete used in a project, the dimensions of walls and floor structures were reduced in the model. The thickness of all concrete walls and regular floor structures were reduced by 50 millimeters, and the dimension of all hollow core slabs in HB1 were reduced from P32 and P27 to P27 and P20 respectively. The new concrete volumes were exported, compiled and the same computations were made as with the original volumes, to allow for comparison to the original volumes.

4.1.2.2 Lowering the concrete class

To find the difference of emitted greenhouse gases dependent on what concrete class is used in the construction elements, calculations were done using the original volumes of concrete in the buildings. Only regularly used concrete classes were considered. Representative numbers were calculated for all the steps between the concrete classes C25/30, C30/37, C35/45, C40/50, C50/60. The calculations were done using the measurements of emitted greenhouse gases gathered from SimaPro [?] and the estimated GWP value for C40/50.

4.1.2.3 Adjusting the amount of steel reinforcement in floor structures

In many cases the amount of concrete can be reduced if the steel reinforcement is increased, as steel has higher tensile strength [27]. Calculations were therefore made to find how the proportions of steel and concrete vary depending on the amount of steel reinforcement in floor structures. This was only done in HB2 as it contains homogeneous floor structures of concrete, while HB1 contains a mixture of homogeneous floor structures and hollow-core slabs which narrows the potential for comparison. The model of HB1 did not contain any valid information regarding steel reinforcement. An assumption was made that the floor structures contained four layers of steel reinforcement, one layer in each direction both at the top and bottom, as is visualised by Figure 4.2.

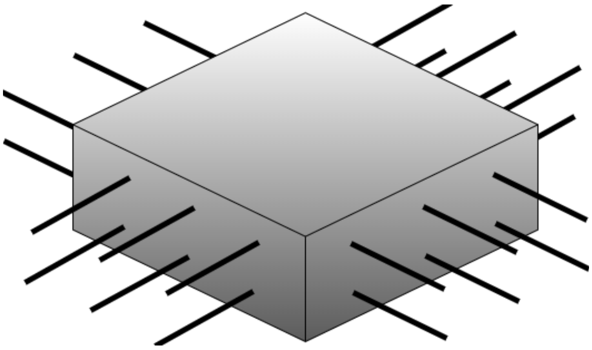


Figure 4.2: Assumed pattern of steel reinforcement in the floor structures of HB2

The two attributes that affect the steel reinforcements capacity the most is the diameter of the individual bars and the distance between them, usually referred to as center distance. Diameters of 12 mm, 16 mm and 20 mm and center distances of 100 mm, 150 mm and 200 mm were used in the study. Different combinations of these were calculated. The calculations aimed to find how much the proportions between steel and concrete varied depending on these two attributes, and how the amount of emitted greenhouse gases varied consequently.

Measurements of emitted greenhouse gases from the steel was gathered from two different sources, Celsa Steel Service AB [15] and JSC B Group [28]. Both EPDs were done for steel specifically manufactured to be used as reinforcement in concrete. As can be seen in these EPDs, the GWP is of vastly differing values at each side of the spectrum. They were chosen for the study as the intention was to find a range of possible values, representing the large differences of various steel products.

4.2 Results of Case Study

4.2.1 Hospital Building 1

Hospital building 1, HB1, is referred to as being representative of a standard hospital building by several structural engineers at WSP. However, it is to be noted that each structural engineer that has discussed the building agrees that all hospital buildings differs much from each other, and there is no such thing as a standard. The consensus is in general that the building has no unique properties that require special measures, which means it does not stand out among the previous projects they have worked on. The structure is mainly constructed in concrete, but it is supplemented with steel columns and beams. This results in a lesser total amount of concrete in the building. The basement walls, ground slab and floor slabs are mainly constructed in concrete and most regular walls are so called sandwich walls. The floor slabs are hollow-core slabs. The total floor area of the building is 300083 m2 including the basement. It should be noted that interconnected floors from existing construction are not included in the calculated floor area, but only the floors directly constructed for HB1.

4.2.1.1 System Boundaries

At the time of writing, the building has not yet been built. The project is currently in the process of assigning technical specifications for construction documents. Therefore, it is subject to possible changes and adjustments. In this study, the current model is the only one being investigated and no follow up regarding potential changes is made.

4.2.1.2 Concrete volumes and emissions of greenhouse gases

All concrete volumes in the BIM model of HB1 was assembled and separated into seven categories depending on it's properties and basic function in the construction. Table 4.2 show the result of said quantification as well as the calculated results of emitted greenhouse gases from these volumes of concrete.

Concrete volume and greenhouse gas emissions HB1			
Building Element	**Concrete Volume [m3]**	**Concrete Class**	**Greenhouse gas emissions [tonne CO2-eq]**
Ground slab	1 545,58	C30/37	486,1
Hollow Core Slab	3 486,38	C40/50	1 137,9
Floor Slabs	3 185,71	C30/37	1 001,9
Backfilled Walls	1 088,40	C40/50	356,4
Regular Walls	4 637,85	C30/37	1 458,7
Columns	229,66	C30/37	72,2
Pile Caps	633,71	C30/37	146,6
Total	14 807,29		4 659,9

Table 4.2: Concrete volumes and emitted greenhouse gases of HB1

4.2.1.3 Reduction of thickness in walls and floor slabs

Two adjustment were made in the BIM model of HB1 to represent a slimmer and more optimized building in terms of concrete thickness. Firstly, the thickness of all walls and regular floor slabs were reduced by 50 millimeters. Secondly, the dimension of the hollow core slabs was reduced, from P32 and P27 to P27 and P20 respectively. No changes were made to the columns or pile caps, hence they are not taken into account in this chapter. Table 4.3 shows the assembled concrete volumes from the adjusted model as well as the calculated results of emitted greenhouse gases from these new concrete volumes.

Reduced thickness and dimension of hollow core slabs HB1			
Building Element	**Concrete Volume [m3]**	**Concrete Class**	**Greenhouse gas emissions [tonne CO2-eq]**
Ground Slab	1 352,87	C30/37	425,5
Hollow Core Slab	3 076,11	C40/50	1 004,1
Floor Slabs	2 906,37	C30/37	914,1
Backfilled Walls	950,00	C40/50	311,1
Regular Walls	3 807,39	C30/37	1 197,5
Total	12 092,74		3 852,2

Table 4.3: Concrete volumes and emitted greenhouse gases of HB1 with reduced thickness of walls and floor slabs and reduced dimension of hollow core slabs

4.2.1.4 Differences in volume and greenhouse gas emissions

The differences in concrete volume and greenhouse gas emissions between the original and the adjusted model were calculated. The results of these calculations are shown in Table 4.4.

Differences with reduced thickness and hollow-core slab dimension				
Building Element	**Reduction of Concrete Volume [m3]**	**Concrete Class**	**Reduction of greenhouse gas emissions [tonne CO2-eq]**	**Percent of total emissions [%]**
Ground Slab	192,71	C30/37	60,6	1,30
Hollow Core Slabs	410,27	C40/50	133,9	2,87
Floor Slabs	279,34	C30/37	87,9	1,89
Backfilled Walls	138,40	C40/45	45,3	0,97
Regular Walls	830,46	C30/37	261,2	5,61
Total	1851,18		588,9	12,64

Table 4.4: Difference in volumes and greenhouse gas emissions with reduced thickness and dimensions of hollow core slabs in HB1

4.2.1.5 Lower concrete class

The concrete classes for all the concrete in HB1 was lowered. Original and new concrete classes as well as greenhouse gas emissions is shown by Table 4.5.

Lower Concrete Class HB1				
Building Element	**Concrete Volume [m3]**	**Concrete Class Reduction**	**Difference in greenhouse gas emissions [tonne CO2-eq]**	**Percent of total emissions [%]**
Ground Slab	1 545,58	C30/37 → C25/30	128,6	2,76
Hollow Core Slabs	3 486,38	C40/50 → C30/37	45,1	0,97
Floor Slabs	3 185,71	C30/37 → C25/30	264,9	5,69
Backfilled Walls	1 088,40	C40/50 → C30/37	14,1	0,30
Regular Walls	4 637,85	C30/37 → C25/30	385,8	8,28
Columns	229,66	C30/37 → C25/30	19,1	0,41
Pile Caps	633,71	C30/37 → C25/30	52,7	1,13
Total	14 807,29		910,2	19,53

Table 4.5: Difference of greenhouse gas emissions with lower concrete class in HB2

4.2.2 Hospital Building 2

Hospital building 2, HB2, is a building with gathered functions within radiology, image diagnosis, treatments and to some extent research within the field of medicine. The activity within the building is therefore not categorized as regular hospital operations and this is evident when analyzing the building's construction and the function of the structure. The building is made for heavy medical equipment such as x-rays and MRI, which expose the construction with large loads and in a addition is very sensitive to vibrations. The building also holds a cyclotron which is made to produce isotopes and has high requirements of the construction's function and capacity. The specific requirements and functions means the construction of the building is not typical for hospital buildings in general, including the projects that WSP has worked on in the past.

The structure of the building is primarily made from reinforced concrete. Because of the particular requirements of the building the structure of the building is oversized compared to HB1. The floors are thicker in HB2 are thicker than the general hospital building to handle larger loads and walls adjoining medical equipment with radioactive activity, such as the cyclotron and x-rays are thicker for the requirements for radioactive management. The floor area of the building is 15980 with the basement included. Surrounding floors of existing buildings that were interconnected to the building are not included in the calculated floor area.

4.2.2.1 System Boundaries

HB2 is an older project as it was finalized in 2016. As a result, the data in the BIM model was not as detailed as the BIM model of HB1. Some data was not possible to extract at all or was insufficient in the project file. The material properties were not up to date with the construction documents and therefore this deviate from the reality. Material properties were estimated and added after council with a structural engineer who were involved in the design process of HB2. These properties apply to concrete classes and the amount of steel reinforcement in the concrete.

4.2.2.2 Concrete volumes and emissions of greenhouse gases

All concrete volumes in the BIM model of HB2 was assembled and separated into six categories depending on its properties and basic function in the construction. Table 4.6 show the result of said quantification as well as the calculated results of emitted greenhouse gases from these volumes of concrete.

Concrete volumes and greenhouse gas emissions HB2

Building Element	**Concrete Volume [m3]**	**Concrete Class**	**Greenhouse gas emissions [tonne CO2-eq]**
Ground slab	1556,42	C30/37	489,5
Floor Slabs	7236,54	C30/37	2 275,9
Backfilled Walls	611,42	C30/37	193,3
Regular Walls	2051,66	C30/37	645,2
Columns	319,90	C30/37	100,6
Pile Caps	340,40	C30/37	110,2
Total	12116,34		3 814,9

Table 4.6: Concrete volumes and emitted greenhouse gases of HB2

4.2.2.3 Reduction of thickness in walls and floor slabs

The thickness of all walls and floor slabs in HB2 was reduced by 50 millimeter in the BIM model. Table 4.7 shows the assembled concrete volumes from the adjusted model as well as the calculated results of emitted greenhouse gases from these new concrete volumes.

Reduced thickness of walls and floor slabs HB2

Building Element	**Concrete Volume [m3]**	**Concrete Class**	**Greenhouse gas emissions [tonne CO2-eq]**
Ground slab	1396,63	C30/37	439,2
Floor Slabs	6361,95	C30/37	2 000,9
Backfilled Walls	530,93	C30/37	166,9
Regular Walls	1668,83	C30/37	524,8
Total	9958,34		3 132,0

Table 4.7: Concrete volumes and emitted greenhouse gases of HB2 with reduced thickness of walls and floor slabs

4.2.2.4 Differences of volume and greenhouse gas emissions

The differences in concrete volume and greenhouse gas emissions between the original and the adjusted model of HB2 were calculated. The results of these calculations are shown in Table 4.8.

Differences with reduced thickness

Building Element	**Reduction of Concrete Volume [m3]**	**Concrete Class**	**Reduction of greenhouse gas emissions [tonne CO2-eq]**	**Percent of total emissions [%]**
Ground slab	159,79	C30/37	50,2	1,32
Floor Slabs	874,59	C30/37	275,1	7,21
Backfilled Walls	80,49	C30/37	26,3	0,69
Regular Walls	1497,7	C30/37	120,4	3,16
Total	**1497,7**		**472,0**	12,37

Table 4.8: Difference in volumes and greenhouse gas emissions with reduced thickness for HB2

4.2.2.5 Lower concrete class

The concrete classes for all the concrete in HB2 was lowered. Original and new concrete classes as well as greenhouse gas emissions is shown by Table 4.9.

Lower concrete class HB2

Building Element	**Concrete Volume [m3]**	**Reduction of Concrete Class**	**Reduction of greenhouse gas emissions [tonne CO2-eq]**	**Percentage of Total Emissions [%]**
Ground slab	1 556,42	C30/37 → C25/30	129,4	3,39
Floor Slabs	7 236,54	C30/37 → C25/30	601,8	15,78
Backfilled Walls	611,42	C30/37 → C25/30	50,8	1,33
Regular Walls	2 051,66	C30/37 → C25/30	170,6	4,47
Columns	319,90	C30/37 → C25/30	26,6	0,71
Pile Caps	350,40	C30/37 → C25/30	29,1	0,77
Total	12116,34		1 008,5	26,46

Table 4.9: Difference of greenhouse gas emissions with lower concrete class in HB2

4.2.2.6 Steel reinforcements

The results from the examination of different layouts of the steel reinforcements in the floors of the HB2. Table 4.10 shows the examination of an average square meter of the buildings floor slab. The average floors thickness was calculated to 0.4 meter. A full table with more detailed calculations can be found in appendix B.

Steel reinforcement volume per square meter floor			
Area of steel reinforcements	**per square meter CD 100mm [m3] ([%])**	**per square meter CD 150mm [m3] ([%])**	**per square meter CD 200mm [m3] ([%])**
12 mm	0,00452376 (1,13)	0,00301584 (0,75)	0,00226188 (0,57)
16 mm	0,00804224 (2,01)	0,005361493 (1,34)	0,00402112 (1,01)
20 mm	0,012566 (3,14)	0,008377333 (2,09)	0,006283 (1,57)

Table 4.10: Comparison of different layouts of steel reinforcements. The percentage represent the amount the steel reinforcement contra concrete per cubic meter

To examine the impact of the steel reinforcements for HB2 the emitted greenhouse gases for one square meter of floor was multiplied by the total floor area of the building. The result is shown in Table 4.11, as well as visualised in Figure 4.3, showing the span of emissions depending on which EPD is used for the calculation.

Emissions of greenhouse gases from steel reinforcements				
Area of steel reinforcements		**CD 100mm**	**CD 150mm**	**CD 200mm**
12 mm	Steel reinforcement [m3]	72,3	48,2	36,2
	GHG emissions (CELSA) [tonne CO2-eq]	205 953,3	137 302,2	102 976,7
	GHG emissions (BGROUP) [tonne GHG eq]	549 027,0	366 018,0	274 513,5
16 mm	Steel reinforcement [m3]	128,5	85,7	64,3
	GHG emissions (CELSA) [tonne CO2-eq]	366 139,2	244 092,8	183 069,6
	GHG emissions (BGROUP) [tonne CO2-eq]	976 048,0	650 698,7	488 024,0
20 mm	Steel reinforcement [m3]	200,8	133,9	100,4
	GHG emissions (CELSA) [tonne CO2-eq]	572 092,5	381 395,0	286 046,3
	GHG emissions (BGROUP) [tonne CO2-eq]	1 525 075,0	1 016 716,7	762 537,5

Table 4.11: The amount of greenhouse gas emissions from steel reinforcements when different layouts are applied

The different clusters of pillars in Figure 4.3 resembles different areas of the cross section bars (12mm, 16mm or 20mm). Each pillar resembles a specific center distance between the steel reinforcement bars (100mm, 150mm, 200mm). The top value seen represented by a line above each pillar is the GWP value extracted from BGROUPs EDP for steel reinforcement while the lowest value represent the value from CELSA. The span where the pillars are filled represent a span of reasonable GWP values used in the current industry climate.

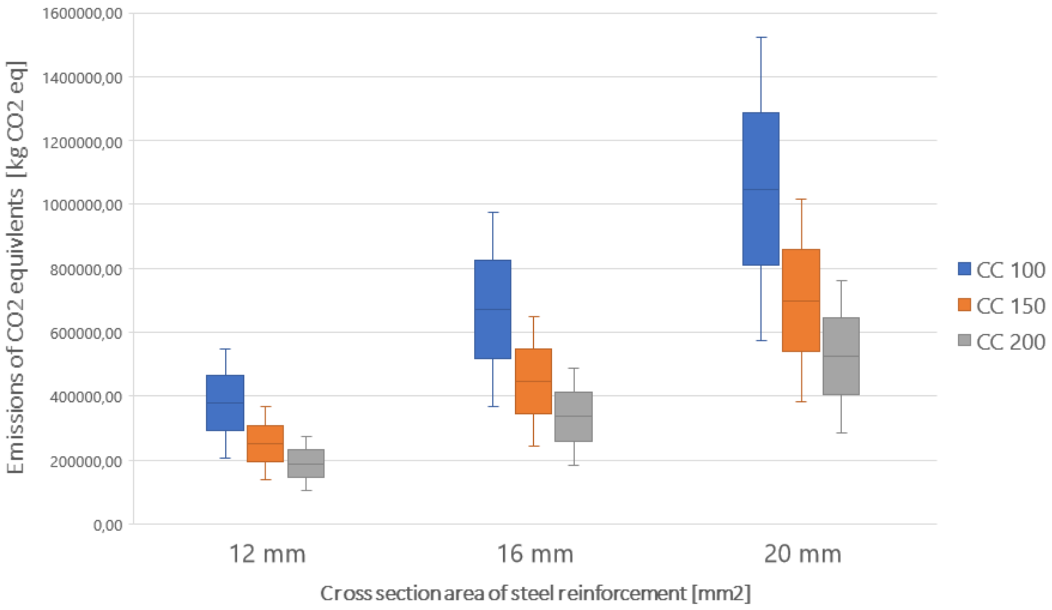
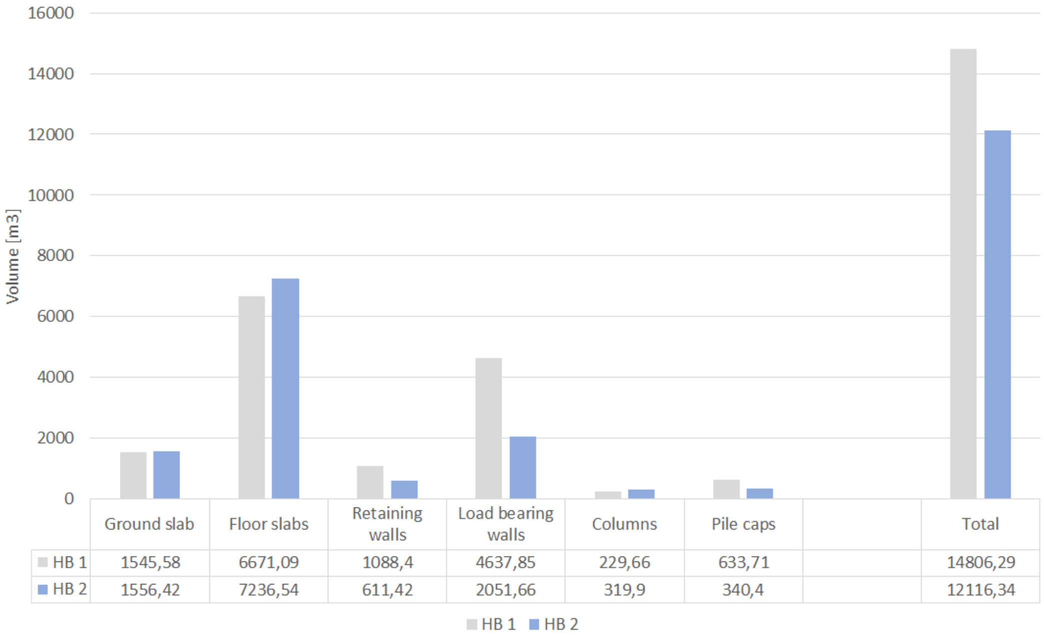


Figure 4.3: Emissions of greenhouse gases from different steel reinforcements layouts in HB2

4.2.3 Comparison of HB1 and HB2

A comparison of the reduction of concrete volume and concrete class of both the buildings was carried out. Due to the substantial difference in size and floor area of the buildings, 30083 m2 and 15890 m2 respectively, the comparison was conducted per square meter. As was established previously, the two buildings have significant differences from one another in terms of concrete volumes, as seen in Figure 4.4. Even if the floor area is almost double in HB2, the volumes of concrete bound in the buildings are about the same. Figure 4.5 and Figure 4.6 shows the differences the reduction of concrete volume and concrete class had in terms of emitted greenhouse gases for both the buildings.



	Ground slab	Floor slabs	Retaining walls	Load bearing walls	Columns	Pile caps		Total
■ HB 1	1545,58	6671,09	1088,4	4637,85	229,66	633,71		14806,29
■ HB 2	1556,42	7236,54	611,42	2051,66	319,9	340,4		12116,34

Figure 4.4: Comparison between the buildings volumes in cubic meters.

4.2.3.1 Reduction of thickness in walls and floor slabs

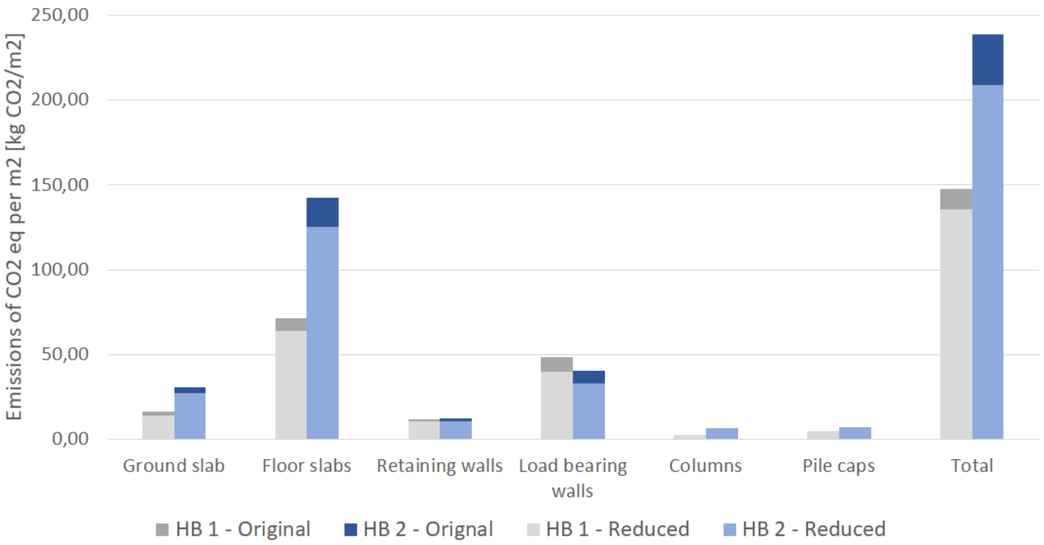


Figure 4.5: Comparison between the buildings of the reduction of greenhouse gas emissions in kg per m2 when reducing the thickness with 50 mm

4.2.3.2 Lower the concrete class

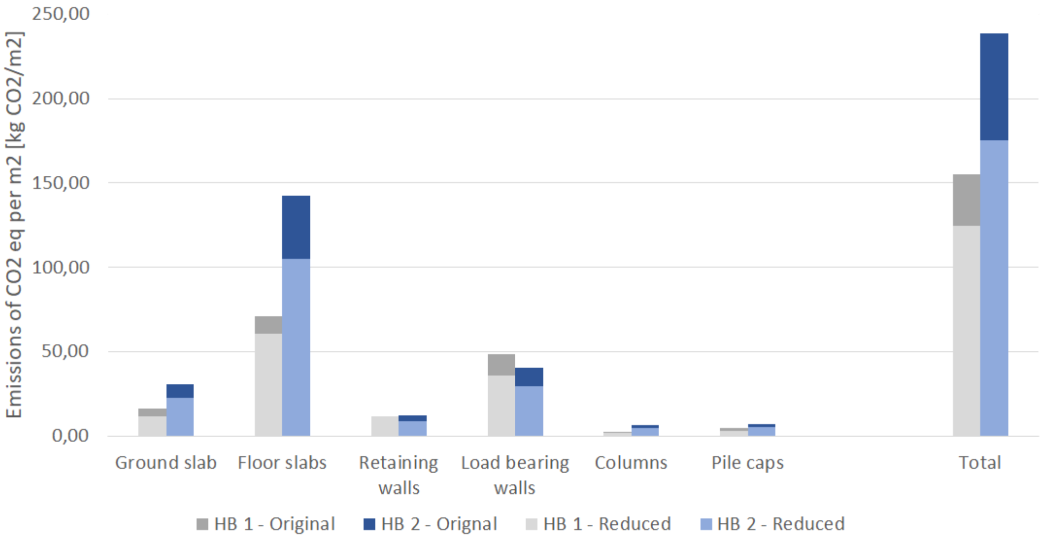


Figure 4.6: Comparison between the buildings of the reduction of greenhouse gas emissions in kg per m2 when reducing the concrete class

5

Discussion

The optimization of the buildings from a sustainable perspective has a range of different applications and potential measures that could be effective. Throughout the design process there are room for improvement when considering building in a more sustainable fashion. However, measures of optimization in the later stages of the design phase are often hindered by other factors, such as already set requirements or financial obstacles.
The case study in this report is a highly theoretical study to visualize and compare the potential of the measures. The magnification of the measures made in this is study is not feasible in most cases but is instead supposed to serve as a starting position when assessing what optimization measures to focus on.

5.1 Hospital buildings

In general, optimization measures of buildings are a very complex matter. Elements included in the structure, such as walls, floor slabs and columns often have several different functions and design factors that must be considered. The interviewees elevated that elements are often designed after other requirements as well, for example to improve acoustic properties. The requisite to follow the functions of the building also need to be considered when designing the structure of the building. This can be observed when comparing the different buildings in the case study. HB2, unlike HB1, is designed for x-rays and research with radioactive activity. The loads needed to support such activity and the requirements to screen off radioactive radiation demands much greater thickness of floors and walls.

When comparing the buildings, the function of the hospitals are a significant factor as the loads they are required to handle differ. HB2 has far less floor area than HB1 but still has more concrete bound to the floors and ground slab, as can be observed in Figure 4.4. Another large factor for differing results is the differing material choices in the structure as well as the fact that HB1 has hollow-core slabs instead of regular floor slabs which are argued to be more effective for large bearing lengths [29]. HB2 being designed for radioactive activity is obviously also a contributing factor to the vast differences in concrete volume of HB1 and HB2. Though, it is hard to evaluate how large a proportion of the difference originate from the different functions of the buildings and how much originate from other aspects.

5.2 Optimization measures

A general reason for over dimensioned elements that are brought up in the interviews is the simplicity of grouping elements of the same nature together and assigning the same properties to all of them, either size or material. For example, when designing the structure of a multi-story house the load decreases with each level, which means you can either reduce the concrete class or size of the element with each floor. This is however almost never the case, instead different floors are put in the same category with same load capacity and properties to simplify the design and production of it. A larger number of unique elements in a building means more complex drawings, which results in more errors when the building is assembled. Simplifying the work at the building site also results in less work hours needed, thus the project becomes less time consuming which is beneficial from a financial perspective.

5.2.1 Reduction of concrete

As seen in the results, reducing the thickness of walls and floor structures can have a significant reduction to the emission of greenhouse gases from the construction of a building. The reduction of concrete could be implemented in several ways. In Sweden, there are many different requirements to adhere to when designing a building. As an example, the acoustic requirements can be the biggest design factor for floors and walls, in front of requirements such as load capacity and stabilization. It is common in the industry to handle the acoustic requirements by increasing the thickness of concrete elements, as the properties of concrete is very compatible when it comes to sound isolation. However, the possibility to replace some of the concrete with another material with the same acoustic properties, but with lower emissions of greenhouse gases, has been elevated in the interviews. Such a measure would be better from a sustainable standpoint but raise problems in other fields, as the production of such elements would be more advanced than a regular concrete wall. More materials in an element is cause for a more advanced manufacturing process, which is according to the interviewees more time consuming and therefore more expensive.

5.2.2 Lowering the concrete class

From the interviews it was clear that the concrete class in buildings often were higher than necessary. The results show that the lowering of concrete class is the optimization measure that in theory reduces the greenhouse gas emissions the most. It is especially clear when analyzing the reduction steps of different concrete classes. The step from C30/37 to C25/30 results in much bigger reductions than any other step. This step was according to the interviewees plausible for many smaller elements, which could have a large impact.

There are several reasons for concrete classes being over dimensioned according to the material experts. Firstly, there are the requirements for exposure class. The higher the exposure class, the higher required quality of the concrete is necessary, thus a higher concrete class. The exposure class is usually determined in the planning program, were the structural engineers influence is limited. Decisions made this early in the design process, like the requirements of exposure class, is harder to adjust at a later stage in the design process without becoming too time consuming and expensive. However most exposure classes includes multiple concrete classes which means there is a possibility to lower the concrete class when optimizing the building at later stage in the design phase.

Secondly, when designing a building one should strive to make the process at the building site as simple as possible. One measure for that is to instead of optimizing each building part individually, you group similar elements in a building and give them the same properties, for example, the same concrete class. This is a design factor that many of the employees at WSP consider when trying to reduce building errors, as seen in appendix C. This will make the process of assembling the building less complex and therefore less time consuming.

5.2.3 Adjusting the amount of steel reinforcement in floor structures

The layouts of the steel reinforcements could also have a significant impact on the emissions of greenhouse gases in a building. As seen in Figure 4.11, the amount of steel reinforcement used in a cross section is much depending on the center distance and cross-section area. However it is very much dependent on the concrete class and the load the floor structure is exposed by. When trying to reduce the amount of greenhouse gases from steel reinforcement the biggest factor is the emissions from the production of the material as seen in Figure 4.3.

5.2.4 Finding the optimum point between the measures

All of the measures discussed above affect the properties of an element, such as load capacity and bearing strength. This makes a comparison of the measures problematic. For example, when reducing the amount of concrete in cross sections the amount steel reinforcement have to be reassessed as a consequence. The same procedure applies when reducing the concrete class of an element. When designing an element in a building, all of these measures mentioned above should be considered to find the the most optimal layout for the set element to eliminate excess material.

5.3 Implementation method of the measures

As for the optimization measures presented in this study, there are many opportunities for improvement. However, this raises additional questions. For example, how are such methods supposed to be implemented and how to change the behavior of a structural engineer to include optimizing from a sustainable perspective into their daily work. This question was raised in the survey conducted at the structural engineering department at WSP, found in appendix C. The general wish from the employees at the company would be an autogenerated, real time screening LCA tool. This would quickly give pointers if there is potential for the project to be further optimized in terms of sustainability, either by reducing the concrete class, the thickness of an element or change the amount of steel reinforcement. The GWP values used for calculations with concrete in this study is provided by WSP and are the same values they use in their tool for screening LCA. The GWP values of those may not be up to date and should, for the better credibility, be reviewed. When comparing the values with other more relevant EPDs it was clear that the GWP values in this study are on the higher end of the spectrum. Due to this, the results concerning greenhouse gas emissions in the case study has a high probability of being lower in reality than in this report.

Another option that was sought after was a quick reference guide to follow while designing a building. The latter option was downgraded by the sustainability coordinator because it would not be as easily accessible and convenient as an autogenerating tool integrated directly into the work interface. These factors are important when changing ones behavior, especially one that has been natural for a long time [30]. Another key factor for implementation of new methods are the effort and how time consuming the new process is. If the new procedure takes too much of an effort to implement, is too advanced and/or demands a lot of time, the chances of changing an employee's behavior is harder.

5.4 EPDs

When evaluating the emissions of the materials used in the buildings, the nature of the used EPDs are a key factor. EPDs for the same type of material can vary largely, depending on several different factors such as differences in the material production or logistics. By choosing the right material, emissions of greenhouse gases can be reduced greatly. As for the EPDs concerning the steel reinforcement the mean value was taken from EPDs provided by two different companies, Celsa Steel Services AB and JSC B GROUP. The GWP values of the different EPDs differs vastly. The main reason for this difference appears to be due to Celsa Steel Services production being more focused on reducing emissions of greenhouse gases, while JSC B Groups in general is less so. The GWP value gathered from JSC B Group may be more in line with the reality as environmentally sustainable products are not fully integrated into the industry yet. The value from Celsa Steel Services may instead be a goal to strive for. The concept of choosing and assessing more sustainable options regarding material in the design phase will become more apparent as new regulations will be put into use in Sweden 2022 [31].

5.5 Organizational barriers

It is elevated both in the interviews and the survey that one of the biggest driving forces for consulting companies like WSP to adapt, is that sustainable requirements are placed directly by the clients. According to the sustainability coordinator, the structural engineers have a drive to find solutions by nature, which results in quick adaptions as new problems arises. But as there are currently little to no initiatives or demands from clients to build more sustainable the development has reached a stalemate. The respondents from the survey is convinced that higher sustainability demands from clients would speed up the implementation of the measures brought up in this study. This may correlate with what kind of contract the consultant is bound to. A study from 2016 show that there is no evidence that different contract forms, such as DB (Design and build) and DBB (Design-bid-build), promote innovative methods and products, regardless if the consultant have more freedom in a DB contract form [20]. This implies that the client is involved in decisions made in the design phase either way. To this moment there has been no reason for clients to build sustainable which has hindered more sustainable options on the market.

In addition, consultants in Sweden are also bound under another kind of contract, ABK09 [32], which function is to simplify the working process for actors in the industry. These standardized contracts sometimes favor more established methods, which are cheaper and easier to execute, and from an economical and practical perspective there are no reasons to change that. The consultants are in a precarious situation, where they may have the best knowledge on how to build more sustainable but are hindered by today's approach of designing buildings. Bringing in new innovations always come with a risk but no real reward for the consultants, even if they are deemed successful in executing a more sustainable product or method in today's financial climate.

One solution to this would be better communication between the actors in the industry. Since the consultants possess knowledge that the client might not, for example for possible sustainable innovations, a dialogue should take place earlier in the design phase with the client. The responsibility should be taken by all the actors in the industry to improve the information flow between the client, the consultant and later the production. Another option would be to reassess the standardized contract the consultants is bound to. The approach being to promote innovative initiatives and new technique to a greater extent.

6

Conclusion

There are opportunities for optimization in the design process of building, including when producing the project planning documents were this study had its focus. However, there is currently limited knowledge and experience regarding how to implement these measures in current projects.

The interview study gathered a lot of suggestions, opinions and information taken straight from experience and reality. Both positive prospects as well as the main obstacles standing in the way of a climate friendlier building industry were elevated. The prospects that were brought up and discussed includes, but are not limited to:

- It is established that concrete accounts for the biggest emissions of greenhouse gases and therefore should be the initial target when trying to optimize building from an environmental perspective.

- In the early stage of the design phase the volumes of concrete amounts to the biggest potential to reduce the GWP emissions from the production stage of the building.

- Finding the optimum point between concrete and steel reinforcements are key when trying to reduce material, and thus greenhouse gas emissions, in a concrete element.

- Lowering the concrete class is an effective method when trying to reduce emissions from concrete. Choosing the lowest concrete class of each exposure class is key. Elements with low exposure class requirements, such as interior walls and beams, should especially be reassessed when trying to optimize.

- Try to break habits of using standardized concrete classes for groups of elements and instead choose the most optimized alternative for each element and its purpose. Small differences may results in large reductions when put in perspective.

- Review whether there are better, more climate friendly materials on the market. This will become more relevant when EPDs are established and standardized.

- The client has the ability to initiate sustainable projects, and it would force structural engineers to start optimizing and reevaluating current design methods.

- The client has the ability to initiate sustainable projects, and it would encourage structural engineers to start optimizing and reevaluating current design methods.

In the case study, it is made clear that the floor structures and walls are the largest culprits of both investigated buildings in terms of emissions, while columns and pile caps stand for a small proportion in comparison. More specifically, in both buildings the main proportion of greenhouse gases originate in the floor structures. It is shown that a reduction of thickness is especially effective when implied to the walls in HB1, while it is more effective on the floor structures in HB2. This indicates that it depends on the function of the building. Furthermore, it is demonstrated that the lowering of concrete classes reduces the emitted greenhouse gases considerably. While lowering any class has a large impact, the step from C30/37 to C25/30 has the largest potential by an extensive margin.

Bibliography

[1] Westlund, P. Brogren, M. Byman, K. Hylander, B. Kellner, J. Linden C. Lönngren, Ö. Nordling, J. Strömberg, L. Winberg, F., Klimatpåverkan från byggprocessen. Stockholm: Kungl Ingenjörsvetenskapsakademin (IVA), 2014

[2] Eglitis-media. Greenhouse gases emissions by country, Lars Eglitis. 2014. `https://www.worlddata.info/greenhouse-gas-by-country.php` (Accessed 25 May 2020)

[3] Boverket. Utsläpp av växthusgaser från bygg- och fastighetssektorn. Karlskrona: Boverket, 2020.

[4] Boverket. Bostäder, lokaler och byggande. Karlskrona: Boverket, 2020.

[5] L.F. Cabeza, L. Rincón, V. Vilariño, G. Pérez, A. Castell.
Life cycle assessment (LCA) and life cycle energy analysis (LCEA) of buildings and the building sector: a review Renew. Sustain. Energy Rev. 29 394–416. 2014. `https://doi.org/10.1016/j.rser.`

[6] Forster, P., Ramaswamy, V., Artaxo, P., Berntsen, T., Betts, R., Fahey, D.W., Haywood, J., Lean, J., Lowe, D.C., Myhre, G., Nganga, J., Prinn, R., Raga, G., Schulz, M., Van Dorland, R. Miller, H.L. (Ed.). Changes in Atmospheric Constituents and in Radiative Forcing Chapter 2. United Kingdom: Cambridge University Press, 2007.

[7] Eurostat, Glossary: Carbon dioxide equivalent. 2018. `https://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Carbon_dioxide_equivalent` (Accessed 25 May 2020)

[8] Svenska institutet för standarder. SS-EN 15978:2011. Sustainability of construction works – Assessment of environmental performance of buildings – Calculation method. Stockholm: SIS Förlag AB, 2011.

[9] Liljnström, C. Malmqvist, T. Erlandsson, M. Fredén, J. Adolfsson, I. Larsson G. Brogren, M. Byggnades klimatpåverkan. Stockholm: Svenska Miljöinstitutet AB (IVL), 2015.

[10] Liljnström, C. Malmqvist, T. Erlandsson, M. Fredén, J. Adolfsson, I. Larsson G. Brogren, M. Byggnades klimatpåverkan, pp. 38. Stockholm: Svenska Miljöinstitutet AB (IVL), 2015.

[11] Liljnström, C. Malmqvist, T. Erlandsson, M. Fredén, J. Adolfsson, I. Larsson G. Brogren, M.
Byggnades klimatpåverkan, pp. 39. Stockholm: Svenska Miljöinstitutet AB (IVL), 2015.

[12] Svensk Byggtjänst. Byggkonstruktörens uppdrag - Omfattning och redovisningsnivå. Stockholm: AB Svensk Byggtjänst, 2012.

[13] Svenska institutet för standarder. Bygghandlingar 90. Stockholm: SIS Förlag AB, 2003.

[14] Bjørn A, Owsianiak M, Molin C, Laurent A. "Main Characteristics of LCA." In Life Cycle Assessment - Theory and Practice, edited by Hauschild MZ, Rosenbaum RK, Olsen SI (ed./s), 9-16. Cham: Springer International Publishing AG, 2018.

[15] Celsa Steel Service AB, Steel Reinforcement products for concrete, [declaration]. Halmstad, Celsa Steel Service AB, declaraction nr: S-P-00305, accessed 16 May 2020.

[16] Bjørn A, Owsianiak M, Laurent A, Olsen SI, Corona A, Hauschild MZ. "Scope Definition." In Life Cycle Assessment - Theory and Practice, edited by Hauschild MZ, Rosenbaum RK, Olsen SI (ed./s), 75-116. Cham: Springer International Publishing AG, 2018.

[17] Fossilfritt Sverige. Färdplan för fossilfri konkurrenskraft - Bygg och anläggningssektorn. Missing publisher and place of publication, 2018.

[18] Svenska institutet för standarder. SS-EN ISO 14020:2000 Environmental labels and declarations – General principles. Stockholm: SIS Förlag AB, 2003.

[19] Sweden green building council. BREEAM-SE New Construction 2017 - Technical Manual 1.1. Missing publisher and place of publication, 2018.

[20] Nyström J. Nilsson J. E, Lind, H. Degrees of freedom and innovations in constructions contracts. Stockholm: Transport Policy, 2016.

[21] Borg, L. Procurment Contracts, Innovations and Productivity in the Construction sector: Five Studies. Stockholm: KTH, 2015.

[22] Baxter, P. and Jack, S. Qualitative Case Study Methodology: Study Design and Implementation for Novice Researchers. Ontario: McMaster University. (Volume 13, Number 4), 2008.

[23] Newman, I. and Benz, C. Qualitative-quantitative research methodology: Exploring the interactive continuum. Board of Trustees, Southern Illinois University Press, 1998.

[24] Bryman, A. and Bell, E. Business research methods. Oxford: Oxford University Press, 2011.

[25] U. Bogenstätter, Prediction and optimization of life-cycle costs in early desgin, Building Research Information 28 (2000) 376-386 `https://doi.org/10.1016/j.enbuild.2016.12.009`

[26] EcoInvent. "Ecoinvent 3" [database)]. Zurich: EcoInvent, n.d. (accessed 27 february 2020).

[27] Suryakanta Padhi, Why steel is used in concrete?, Suryakanta Padhi, 2016. `https://civilblog.org/2016/02/16/why-steel-is-used-in-concrete/` (Accessed 14 June 2020)

[28] JSC B Group, Reinforcement Steel Products, [declaration]. Oslo: The Norwegian EPD Foundation, declaration nr: NEPD-2060-929-EN, accessed 16 May 2020

[29] Buettner, Donald R. and Becker. Roger J., PCI Manual for the design of hollow core slabs, second edition, Chicago PCI, 1998.

[30] Schalk, R., Campbell, J.W. and Freese, C. "Change and employee behaviour"Leadership Organization Development Journal, Vol. 19 No. 3, pp. 157-163. 1998.

[31] Regeringen. Klimatdeklaration för byggnader. Ds 2020:4. 2020.

[32] Byggandets kontraktskommitté. ABK 09 Allmänna bestämmelser för konsultuppdrag inom arkitekt- och ingenjörsverksamhet. Stockholm: Svensk byggtjänst, 2010.

A

Appendix

A.1 Interview with the group manager

How can companies affect the client choice in investing in a more sustainable product?
WSP must enter at an earlier stage. They try to open up a dialog with clients about sustainable building, but the project is moving at a slow pace. Generally, the cost at hand still weighs heavier. The cost of a constructor from the beginning of a project is to expensive. Constructors have not been present at this early stage of a design phase and therefore there is no reason to change a working concept. However, the possibility to affect the choice's of an architect and propose different materials, shrink and optimize dimensions and offer other solutions at an early stage would make a great impact. GC1 believes that this is an obstacle to overcome and is the sole purpose that the development is slow.

Why are buildings often oversized?
It is easy to get into old habits and use experience and methods that are proven. For example, you decide a thickness or dimension that may or may not be optimized at a later stage, depending on if there is enough time. It also becomes easy and convenient for the consultant. This also results in a less time-consuming project which results in a cheaper investment for the client. Something that clients appreciate is when it costs less money.
You also have to take the risk versus optimization into consideration when making designs. The more elements that are optimized, the greater the risk that something goes wrong. It also results in a greater workload for the designer and a greater work intensity. It is easier, more comfortable, safer and less time-consuming to oversize.

Is there an economic benefit in optimizing?
The direct material cost decreases. However, it must be weighed against the risk and hourly cost it takes to optimize. Error sources in the design increase with each optimization. Simplicity must also be taken into account, saving time saves money. GC1 believes the company should start optimizing the more obvious things. Focus on the parts where there is great potential for optimization.

Where is the greatest potential for improvement? One should especially look at the basement levels. In walls and baseplates there is great optimization potential. The joints can also be optimized. Oversized to reduce sound penetration.

Could be replaced to some extent by other materials. It would probably be good to optimize the water-cement ratio , which is also done in some projects at WSP according to him. But even here, we must weigh the risk of creating more sources of error. It also raises another issue. The robustness of the building is suffering, which may reduce the life of the building.

Communication between calculation and modeling results in that much is estimated. Does this cause problems from a sustainability point of view?
It is optimal to calculate first and then optimize but is rarely seen in the reality. First, a dimension is estimated and then calculations are made to see if it meets all requirements. If there is time it may be optimized. It would probably have been better to do the opposite, but the cost, in both time and money is too great.

A.2 Interview with material experts

How can we make the building industry more sustainable?
ME3 instantly elevates the questions: "What is meant by sustainability in the context?" "Is it solely about CO2 equivalents or a broader context of sustainability?" According to ME3 the society focuses too much on CO2 equivalents. He believes that sustainability is more a question of something that lasts for a long time and is used well during that time. He uses biofuel as an example of how society is staring blindly at something that is not fully sustainable. ME3 lists four basics for sustainability according to him: Optimize, reduce building errors, prolong lifetime and the possibility to adapt (use existing resources). ME3 also take up high-speed rail as an example of something that is considered environmentally friendly but which has huge emissions during construction. He considers it as technology that should be built and produced in the future when better technology and more knowledge is available.

M1 believes that it is virtually impossible to build a house environmentally friendly on the short time spans that are common in the industry nowadays, proposing one year as an example. The content of cement is difficult to adjust and make efficient to dry out quickly. In some cases, like for bridges, too high contents of cement are not allowed, which is due to a lack of calculation basis when the calculation methods for these cement contents have not been properly investigated.

M1 believes we need to be better at optimizing buildings. He gives an example: if you lower the content of cement in concrete but increase content of ballast you increase the thickness of the element. This may still be environmentally worthwhile. If it is an exterior element, it can also possibly bind carbon dioxide. M1 says that construction time controls more than the exposure class when it comes to house building.

If you can be involved in the planning stage early, you can be clear that the construction time will be longer if the climate impact of the construction is to be minimized. ME1 talks about a project for Skanska in Luleå where they will build climate smart and well optimized - he thinks it is exciting to see if it can last the time.

Various contracting forms were also addressed. In general, ME1 believes that we are too far away from the contractor and should cooperate more with them. "We bark at them and they bark at us," he says. General contract - then you usually do full deeds without the contractor being involved. Missed what was said about the contract.

ME1 believes strongly in optimizing simple things as a start, such as pillars and walls. Calculation methods spins possibly a good tool.

Is there great potential for improvement in different cement types? The dehydration of concrete floors is a problem. The content of cement is therefore most easily reduced in walls and columns. The use of base cement (cement made by fly ash) is taken up as an opportunity to build more sustainable. They agree that it the properties is slightly different compared to ordinary (Portland) cement, for example the drying time. ME2 believes that one should be careful about using base cement, especially considering the dehydration, which is difficult to predict as the new type of cement is untested. That point of view is shared with the building industry. ME2 emphasizes that it is difficult to predict how cement dries and that it differs form project to project.

About cement types that may provide the same capacity in the end. Where is the base cement produced? ME2 replies that Cementa has production in Skövde and Norway. But is very little base cement in western Sweden and Skåne. In heavy constructions, base cement is not used, as construction cement is used. Must be separated! Building cement can be replaced with base cement in many cases which can be good.

Are the constructors at WSP aware of the choices they make? For example, about exposure classes? Is there anything to gain by increasing knowledge? ME1 thinks it is more about getting the idea of optimization implemented with the constructors. The problem is that you should still be able to win projects - and projects must not take too long as it becomes too expensive. However, he believes that with increased knowledge it takes less time and that it is important to find out how to optimize effectively. Optimization also applies to wood and steel, not just concrete. He points out that WSP is still governed by what the clients want.

Is optimization worth it? According to ME3 it is vital to reflect upon the function of the design or what different materials contributes. With concrete, the total height may be half a meter lower, because with wood as material the floor structures often become thicker. In some cases it is easier to rebuild a concrete frame than a wooden frame. So it is not always certain that wood is better.

What tools can we use to optimize building? ME1 believes in tools where one can very easily see the difference in climate imprint on different elements, such as pillars, without having to go into tables or other databases. He believes that they should not be program-specific, but serve as support functions for the various programs used. Grasshopper is an alternative to this. But someone has to decide how the process to build sustainable is structured, just like how the process takes other requirements into account. That is what is needed here and now. ME1 thinks that you should take one step at a time, ie focus on CO2 equivalents initially, and only once you have got it working well can you go ahead and build on it. He also thinks it is good to start with only materials, then include other phases like transport at later stage.

Do WSP have any influence with our prefab manufacturers? Do they want even faster dehydration?
ME2 doesn't think so. They only have a certain number of product lines to cast the concrete on and therefore want it to harden as fast as possible to accommodate a new casting. M1 believes that prefab is often optimized already, as manufacturers saves resources. A general feeling is that there is not much to gain environmentally in prefab. He believes that a climate-based study of the difference between prefab and site casting would be interesting, but only for buildings with smaller span widths as prefabs can handle much longer span widths than site casting. M1 believes that prefab has less climate impact because they can and have been optimizing the product at the manufacturer.

A.3 Interview with sustainability coordinator

Where can the largest improvements be made in building design from a sustainability perspective?
To reduce the environmental impact of buildings, the sustainability coordinator said that the improvements she believes can garner the largest results is in the reduction and reuse of material. In new constructions the ambition should be to reduce all materials that will be used in the building. However, a focus on mainly minimizing the concrete and steel reinforcement is warranted as it contributes with the largest emissions in almost all the LCAs she performs. She says that the main priority in new constructions should be to reduce material, and that the secondary priority should be to reuse material. Additionally, she believes it is important to take future reuse into account today already, in other words to design buildings that easily allow for material reuse in the future.

What are the main obstacles for this to happen and how to overcome them?
The sustainability coordinator believes that a lot of hindrance lays in the mindset of people. She compares it to other major changes that has happened in the industry, and noted that the resistance against it is similar this time. It is easier to see the obstacles than the possibilities, and as a result a lot of people believe it will make future buildings worse. This doesn't have to be the case according to her. However, there is a lot of people interested and involved in sustainability questions already, and they already do a lot to reduce climate impact. Therefore she argues that it is important to reach the people that are not interested in sustainability, as that's where the largest behavioral changes can be made.

A reform and change of standard is always a struggle, but it is necessary. As it is now, there is a tendency to use more material than is necessary to ensure that requirements are met. According to her, even small reductions in the amount of concrete or steel reinforcements can have a large impact and should therefore be made. She believes and understands that a reform like this contribute to a form of nervousness for the constructor, as they are responsible for the final product and any issues that may arise. They also have AMA and technical requirements to take into account. Because of this, new methods and standards to minimize the chances of errors must be worked out in order for constructors to feel comfortable doing it. She also believes that constructors will become less inclined to over-dimension if they receive a larger insight into how large of an impact their daily tasks have. New tools that easily show the difference in environmental impact to assist these daily decisions and show the importance of their work could have a large impact to change their mindset according to her.

She believes it is crucial to try to bring experience from one project onto the next one. Presently, people tend to do as they've always done. If the client requires something, people are quick to find a solution, but it is only done if the client requests it. In a lot of cases, those solutions are then cast aside for future projects. If there are any minor changes in one project, or discoveries of how to do things differently, it is very important to bring them into the next project as well.

She also brings up that there's generally very short timespans in projects which means that construction engineers are not given much time to optimize for sustainability. This does in turn become a matter of cost, as it takes time and effort to optimize. She argues that this could eventually become easier with changes to current frameworks and regulations, but notes that she is not qualified to make such an assertion with certainty.

How can these changes be made effectively?
In general, the most effective way to see changes is if the client starts requesting them, according to her. She does not believe more documents, checklists or reference guides would be effective as they tend to be forgotten or simply not prioritized. A supervisor or specialist within sustainability to whom constructors can turn with questions could be good initially, but she does not believe it would be functional in the long run.

Currently, her department enters the projects very late. At that stage, the decisions have already been made and there's little to no possibilities to make an impact. It's harder to change things that have already been decided than it is to influence a decision that has not yet been made. She believes it would be beneficial if her department could be an active part in the earlier stages of the projects to consult clients regarding how to reduce the environmental impact. Additionally, she argues that her department can contribute the most before the requirements of the building is set in stone. Her ambition is for optimization from a sustainable perspective is taken into account from the beginning of the design phase.

She also brings up the importance of improved communication and collaboration between different departments, specifically her department and the constructors department in this case. It is beneficial to know from who and where certain expertise can be found. Therefore she believes it is important to create opportunities for people from different departments to introduce themselves to each other. It would minimize the gap between the departments.

Autogenerated LCA analysis that can be run throughout the projects different development stages would also be valuable according to her. It would provide data and an overview of potential changes that could be implemented in future projects. For her department it would be great as it would be helpful to visualize when and where changes occur during the project. She also thinks it would be valuable for constructors as it could assist them in visualizing the sustainable perspective of changes. However, she argues that there is a risk of people not using such a tool, even if it is just a slight bit inconvenient. Therefore it needs to be made very pedagogic, visually simple and that it works as a background tool that doesn't require much attention from the constructor.

How can sustainability be sold to a client?
She argues that it is important for WSP to have a few front-edge projects where sustainable ideas were implemented successfully, as it will establish the approach that it is possible. These initial projects should be made with clients that have an interest. She does however acknowledge that it might be difficult to find clients interested in these initial projects. Her suggestion is that together with the regular offer, an alternative and more sustainable offer could be made. If WSP already has a sustainable offer available it is much easier for the client to pursue a more sustainable path, as the solution is already available. Even if it could be more costly to them, this could open up certain clients to the idea of making their projects more sustainable. According to her this could potentially have a positive side effect. Several constructors and other workers would be involved in such a project, which could help spread interest in such projects to the rest of their departments.

She also believes the business managers have a large responsibility. They have the possibilities to create a dialog with clients to inform them about sustainability and what is possible. Another alternative is to inform clients of matters that could have been improved in current or previous projects to create an understanding of possible changes that can be made. She believes both of these alternatives could spur interest.

B

Appendix

B.1 Calculations for steel reinforcements in HB2

HB2 Floors	**Total Area**	15980	[m2]			
	Average thickness of floors	0,4	[m]			
	Center distance	[mm]		**100**	**150**	**200**
Area of steel reinforcement beams [mm]						
12	**Steel reinforcements volume**	[m3]		72,290	48,193	36,145
	CO2 emissions (CELSA)	[kg CO2-eq]		205953,31	137302,21	102976,66
	Weight per m3 (CELSA)	[kg/m3]		84,53	56,35	42,27
	CO2 emissions (BGROUP)	[kg CO2-eq]		549027,00	366018,00	274513,50
	Weight per m3 (BGROUP)	[kg/m3]		86,22	65,90	49,42
16	**Steel reinforcements volume**	[m3]		128,515	85,677	64,257
	CO2 emissions (CELSA)	[kg CO2-eq]		366139,22	244092,81	183069,61
	Weight per m3 (CELSA)	[kg/m3]		150,28	100,18	75,14
	CO2 emissions (BGROUP)	[kg CO2-eq]		976048,00	650698,67	488024,00
	Weight per m3 (BGROUP)	[kg/m3]		153,28	117,15	87,86
20	**Steel reinforcements volume**	[m3]		200,805	133,87	100,40
	CO2 emissions (CELSA)	[kg CO2-eq]		572092,53	381395,02	286046,27
	Weight per m3 (CELSA)	[kg/m3]		234,81	156,54	117,40
	CO2 emissions (BGROUP)	[kg CO2-eq]		1525075,00	1016716,67	762537,50
	Weight per m3 (BGROUP)	[kg/m3]		274,56	183,04	137,28

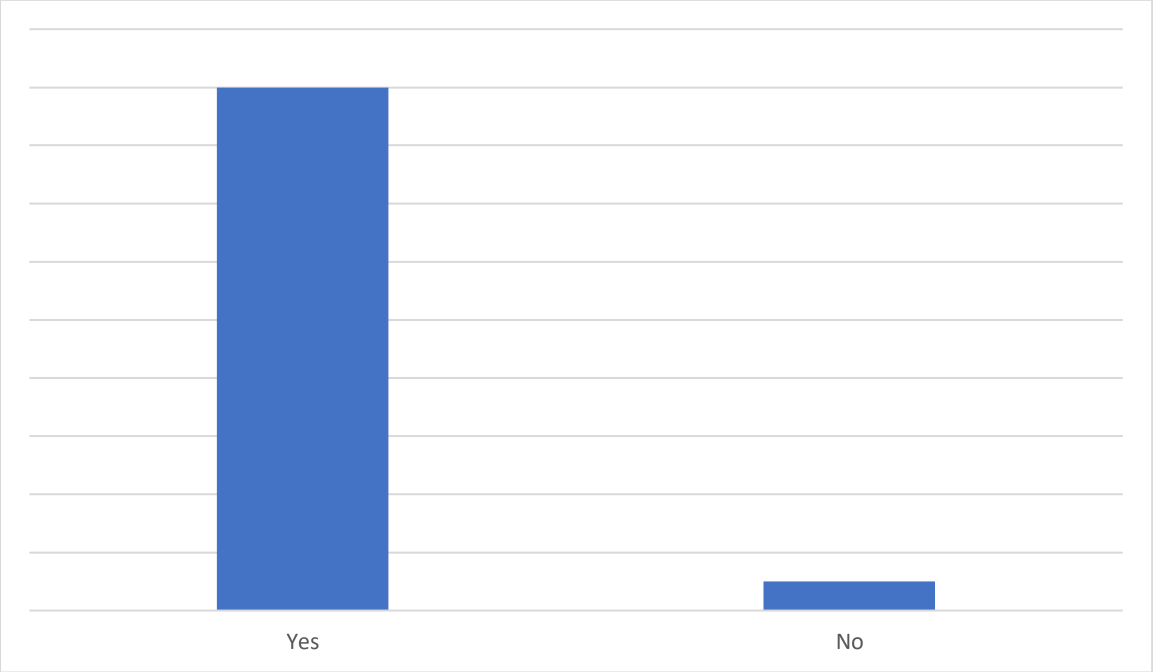
C

Appendix

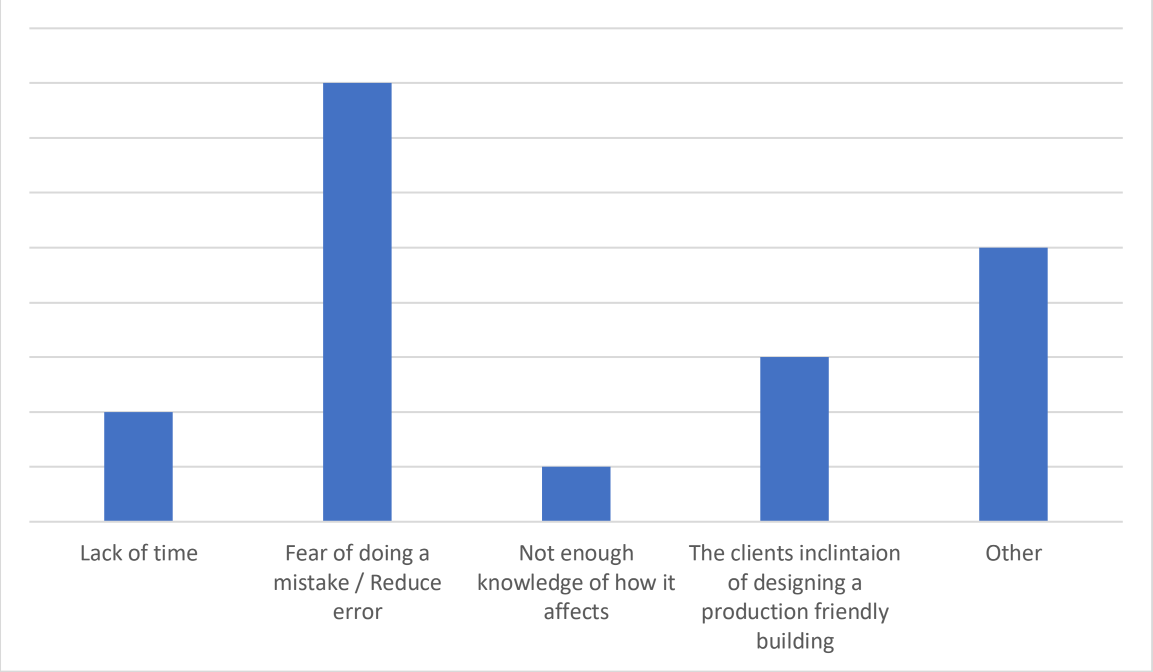
C.1 Survey of the structural designers at WSP

As a supplement to the interviews, a short survey was also sent out to the structural design department at WSP i Gothenburg. The results for the survey is presented below. In total there were 19 respondents to the survey.

1. **Do you feel like the sometimes over dimension a building or element when it comes to load capacity?**



2. **What is that drives you to over dimension?**

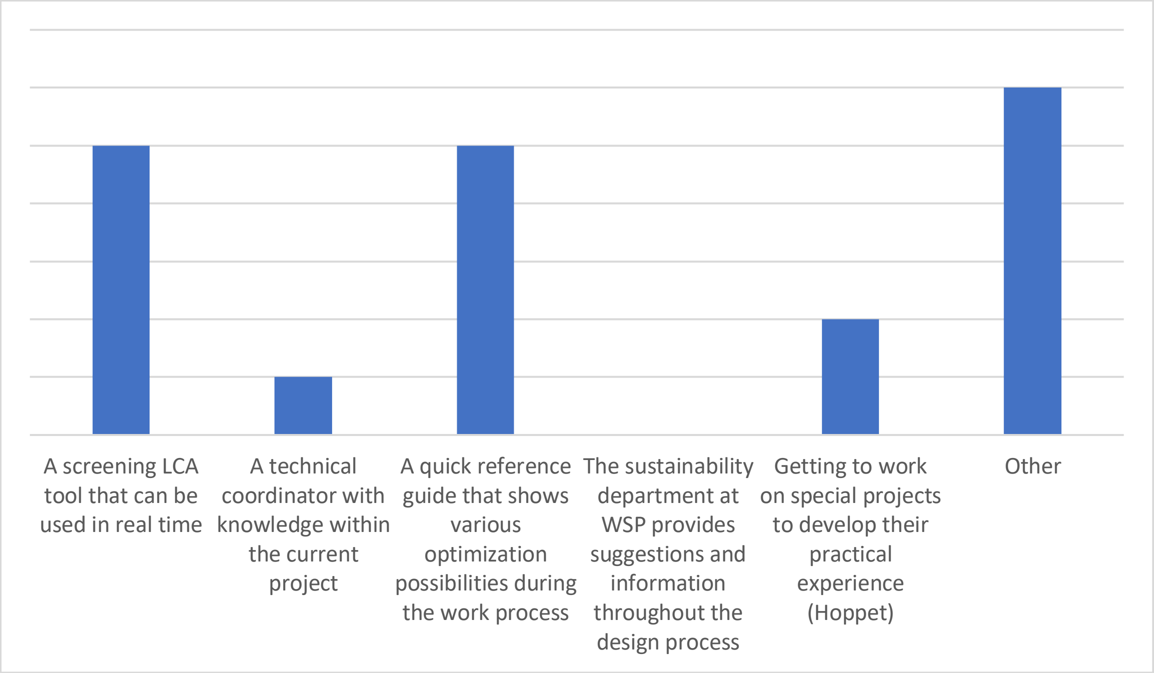


Other

All points listed above apply.

The client’s requirements of a certain utilization range

3. What do you think would help WSP become better to climate optimize buildings?



Other

All points listed above apply.
Clarity and planning from clients.
Own commitment, curiosity, role models, leadership and knowledge.
All the above. I would also like to add that engineers who have lots of design experience are able to come up with more efficient solutions if they understand how the structure works and what can be optimized.