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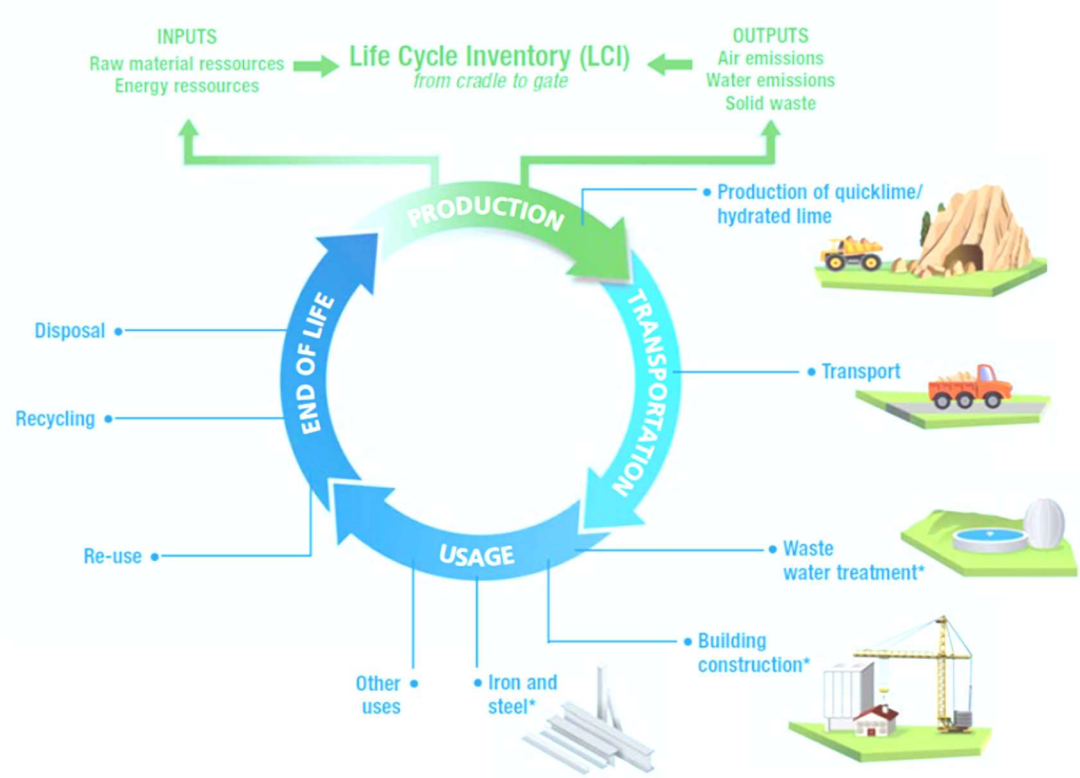

Advantages of steel as a building material from a sustainability perspective

Master's thesis in Structural Engineering and Building Technology

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Department of Architecture and Civil Engineering
Division of Structural Engineering
CHALMERS UNIVERSITY OF TECHNOLOGY
Master's Thesis ACEX30-YY-NN
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Cover:
The life cycle of steel

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ABSTRACT

It is perhaps not possible to say that a material is the most sustainable always and everywhere. It has to do with the application. It is vital with "the right material in the right place," and a hybrid will probably be the best solution, even in the future. Steel is a sustainable material, and in some cases, the most sustainable choice. This is partly based on the fact that steel is a circular material, which means that it can be reused and recycled repeatedly. Steel allows a long service life, since its properties usually are unchanged unless it is exposed to fire, corrosion or fatigue. It is hard to compete against steel if there are requirements for large open surfaces, slim constructions, high loads, or if explosion must be considered

Just during the past two years, the environmental focus and knowledge has increased, and many companies are now working purposefully to reduce their impact on the environment. The awareness of the construction materials impact on the environment is also something that has increased recently. There are ongoing projects in the steel industry focusing on reuse and lowering the CO_2-emissions from the production.

Sustainability is a broad concept, and according to literature studies, sustainability in the construction industry is, among other things, about efficiency, flexibility and longevity.

Something that is missing is a common practice/standard for calculating the environmental impact of materials in the construction industry. Depending on goal and scope, the LCA method is used differently, and few operators consider the entire lifecycle. Difficulties in collecting data and interpreting results mean that many persons do not use the method, at least not to its full extent.

Interviews indicate that economy is of higher priority than the environment in the building industry today. Some companies stand out and invest heavily to reduce the environmental impact, but for all companies to invest in the environment, and reach climate neutrality 2045, requirements and incentives are needed.

Conclusions are partly based on interviews that have been carried out to get an indication of today's situation. It is essential to point out that it is only an indication due to the number of interviews.

The aim of the thesis was to find the advantages of steel as a building material from a sustainability perspective, which is limited to the environment and economy. The report is limited to the Swedish building industry and steel.

Keywords: Steel, sustainability, circular material, LCA, construction industry

Fördelar med stål som ett byggnadsmaterial ur ett hållbarhetsperspektiv

Examensarbete inom masterprogrammet Konstruktionsteknik och Byggnadsteknologi

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SAMMANFATTNING

Det är kanske inte möjligt att säga att ett material är det mest hållbara alltid och överallt. Det har att göra med applikationen. Det är viktigt med "rätt material på rätt plats", och hybrid kommer förmodligen att vara den bästa lösningen, även i framtiden. Stål är ett hållbart material och i vissa fall det mest hållbara valet. Detta är delvis baserat på det faktum att stål är ett cirkulärt material, vilket innebär att det kan återanvändas och återvinnas upprepade gånger. Stål kan ha en lång livslängd, eftersom dess egenskaper vanligtvis är oförändrade såvida det inte utsätts för brand, korrosion eller utmattning. Det är svårt att tävla mot stål om det finns krav på stora öppna ytor, små dimensioner, stora laster eller om det finns risk för explosion.

Bara under de två senaste åren har miljöfokuset och kunskapen ökat, och många företag arbetar nu målmedvetet för att minska deras miljöpåverkan. Medvetenheten om konstruktionsmaterialens påverkan på miljön är också något som har ökat nyligen. Det pågår bland annat projekt inom stålindustrin med fokus på att fånga och lagra CO_2-utsläpp från produktionen.

Hållbarhet är ett brett koncept, och enligt litteraturstudier handlar hållbarhet inom byggbranschen bland annat om effektivitet, flexibilitet och livslängd.

Något som saknas är en allmän praxis/standard för att beräkna miljöpåverkan av material i byggbranschen. Beroende på mål och omfattning används LCA-metoden på olika sätt, och få operatörer överväger hela livscykeln. Svårigheter med att samla in data och tolka resultat innebär att många personer inte använder metoden, åtminstone inte till fullo.

Intervjuer indikerar att ekonomin har högre prioritet än miljön i byggbranschen idag. Vissa företag sticker ut och investerar mycket för att minska miljöpåverkan, men för att alla företag skall investera i miljön och nå klimatneutralitet 2045 krävs regelverk och incitament.

Slutsatser är delvis baserade på intervjuer som har genomförts för att få en indikation av dagens situation. Det är viktigt att påpeka att det bara är en indikation på grund av antalet intervjuer.

Syftet med avhandlingen var att hitta fördelarna med stål som byggnadsmaterial ur ett hållbarhetsperspektiv, vilket är begränsat till miljö och ekonomi. Rapporten är även begränsad till svensk byggindustri och stål.

Nyckelord: Stål, hållbarhet, cirkulärt material, LCA, byggindustri

Contents

Preface

This master's thesis was carried out during spring 2020 at the department of Architecture and Civil Engineering, Division of Structural Engineering, at Chalmers University of Technology, Sweden. The thesis was made in collaboration with SBI in Stockholm and evaluates steel as a construction material from a sustainable perspective.

I would like to extend a big thank you to SBI for giving me the opportunity to do this work. Thank you Rutger Gyllenram, Björn Åstedt, Erik Forsgren and Peter Salomon, who have supported me during the entire project and spending a lot of time and dedication to form this thesis. Also, thank you, Mozhdeh Amani, my examiner for your support and advises.

Ahmad Abdul Sater and Oskar Thor it has been a pleasure to have you as opponents, thanks for valuable input.

Finally, thanks to all who have contributed with knowledge, thoughts and experience, through interviews and conversations. I am incredibly grateful for all help during the entire work.

Gothenburg June 2020

Hanna Brynhildsen

Notations

BIM Building information model

Circular construction industry A construction industry without waste, with the goal of reducing greenhouse gas emissions. Used materials are either rehabilitated, recycled, or reused. New buildings are constructed with reused material, and the material flow is analysed from a holistic perspective.

Circular material Material that can be rehabilitated, recycled and reused, enabling material flow without waste

CO_{2e} Carbon dioxide equivalents

Downcycling Recycling materials for less valuable use, for example, from building products to fillers.

LCA Life cycle assessment, a method used for evaluating the environmental impact.

SBI The Swedish Institute of Steel Constructions

Upcycling To recycle materials for more valuable use. The material can get higher strength properties after recycling

1 Introduction

1.1 Background

The environmental focus has increased significantly in recent years, and climate changes happen faster than expected. Europe has presented a strategy "EU GreenDeal," including a roadmap with key actions to reach climate neutrality 2050 in combination with a sustainable economy (European Commission 2020).

The building sector is responsible for 33% of the CO_2-emissions and accounts for 40-50% of raw materials extraction worldwide (Janczyk 2020).
Energy conservation and energy efficiency have been two of the main focuses in the building industry when talking about environmental impact. These areas are now quite optimized, and awareness of the importance of construction materials has increased recently.

Due to its low weight, steel offers advantages in transportation and erection, as well as reduced requirements at the foundation compared to concrete. It is easy to perform renovations, and extensions can easily be made on top of existing buildings without overloading the foundation. With the strength-weight ratio in mind, steel is a strong material which enables for long spans and large free surfaces. It can be reused and recycled repeatedly without loss of strength.

CO_2-emissions from the production are often highlighted in the sustainability discussions, and from that point of view, timber is the best option today. But one fundamental idea is that the entire lifecycle should be considered. Steel is a circular material with a long lifespan, and unlike timber, steel can be upcycled. In terms of finance, there are often discussions about whether it is more expensive to build in timber, compared to steel and concrete, or not.
Considering sustainability, it is essential to include both environmental, economic, and social aspects. From that perspective, all three industries, steel, timber, and concrete, have their point of view.

It is perhaps not possible to say that a material is the most sustainable always and everywhere. It has to do with the application. The Swedish steel industry, on the one hand, has presented a roadmap for a fossil-free and competitive steel industry in Sweden and states that steel is a sustainable construction material (Jernkontoret 2019).
On the other hand, there are those with different opinions.
Anna Denell, for instance, who was named "Sweden's best sustainability manager" by Aktuell Hållbarhet, says that timber is the most sustainable material (Vasakronan 2019).

To cover the gap, SBI wants to find advantages of steel as a building material from a sustainability perspective, how it appears in a life cycle analysis, and what the perception in the building industry looks like.

1.2 Aim and objectives

The aim of the project is to find out how steel can contribute to sustainable solutions, and what the perceptions in the building industry looks like in comparison with SBI's perceptions of steel.

The following objectives have been developed

- Investigate what sustainability means for the construction industry.
- Investigate in which situations steel is chosen as a construction material.
- Investigate how steel can contribute to a sustainable solution
- Find case studies where steel have been used in more sustainable ways

1.3 Hypothesis

- There is no consistent application of LCA in the construction industry today
- Today, economic interests are a priority over the environment
- There are cases where steel is the most sustainable solution
- The environmental benefits of reused steel make up for increased handling costs

1.4 Method

Initially, a literature study of existing reports, case studies, and articles was conducted to obtain information about steel and sustainability, and to get an overview of ongoing discussions.

After that, since the environmental focus has increased in recent years, and the idea of a circular construction industry is quite new, interviews were conducted to get an indication of today's situation.

To find advantages of steel as a building material from a sustainability perspective, the interviews and discussions were divided into 4 sections. LCA: to find out whether environmental grading schemes are used in a consistent way to evaluate different materials. Sustainability: to find out which factors affect whether a material or solution is sustainable or not. Economy and environment: to find out how they are weighted in relation to each other, and if customers are willing to pay extra for the environment. Steel: to find out in what situations and for what reasons steel is chosen, considering sustainability.

Simultaneously, ongoing projects, considering reuse of steel and climate neutrality, has been followed to cover the gaps.

Meetings, where particular issues have been discussed and sorted out, have taken place continuously with supervisors at SBI and Chalmers.

During the final stage, conclusions have been drawn about the question of whether steel is a sustainable material or not.

1.5 Limitations

The work has been limited with regard to Chalmers specifications of degree projects in the civil engineering programs, which pertain to 30 credits and correspond to 20 weeks of work.

Since the concept of sustainability is very extensive, it has been limited to the environmental and economic aspects.

The thesis has focused on whether steel can contribute to sustainable constructions in the Swedish construction industry.

A deepening in LCA, LCC, other materials, and the different production methods of steel has not been done.

The study will be limited to carbon steel with strength class S235-700 since this is standard steel that is covered in Eurocode.

2 Sustainability

In 1987 the report "Our common future" by the World Commission on Environment and Development was represented, consisting of a strategy that united development and the environment. This was partly due to increased awareness of limited natural resources and the negative impact of human activities on the planet. Alternatively, the way of living had to change to ensure a better quality of life for everyone, even for future generations. The term sustainability was represented for the first time in the report as "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (United Nations 1987). What was unique about the report was that it focused on achieving environmental goals in combination with, not separate from, the achievement of economic and social milestones. This definition is of great importance and serves as a basis in most of the sustainability definitions that have been developed to emphasize different approaches and priorities.

2.1 The concept of sustainability in the construction industry

In the mid-1990s, sustainability was introduced in the construction industry (Gundes, 2016), and previous focus areas, costs, quality, and performance, were supplemented with health and the environment. According to the World Green Building Council (World Green Building Council, 2020), the construction industry can contribute to achieving 9 of the 17 sustainable development goals defined by the UN to attain a better future for everyone, which are as follows

3: Good Health and Well-being
7: Affordable and Clean Energy
8: Decent Work and Economic Growth
9: Industry, Innovation and Infrastructure
11: Sustainable Cities and Communities
12: Responsible Consumption and Production
13: Climate Action
15: Life on Land
17: Partnerships to achieve the Goal

Since the 1990's, a wide range of sustainability definitions have been developed, two of them are listed below

- "Sustainable building is the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building's lifecycle from siting to design, construction, operation, maintenance, renovation and deconstruction" (US EPA,2020).
- "Sustainable construction refers to construction activities whose negative impacts are minimized and positive impacts maximized so as to achieve a balance in terms of environmental, economic and social performance" (Mirsaeedie, 2012).

The first definition complements the concerns that already exist in the construction industry by focusing on the environment and highlights the importance of including the entire life cycle. The last description, on the other hand, consists of all aspects, but do not mention the life cycle perspective.

To adapt sustainability definitions into the construction industry in practice, the authors of the article "Sustainability in Building and Construction: Revising Definitions and Concepts" have created a model where essential aims are represented for the different aspects of sustainability, which in this case additionally includes a technical perspective. The model looks like the following (Mirsaeedie, 2012)

Environmental aspects of sustainability
- Reduce Pollution
- Reduce Waste
- Consumption
- Recycling
- Compatibility

Economic aspects of sustainability
- Construction Speed
- Programming
- Reduce Waste
- Profit

Social aspects of sustainability
- Public Participation
- Flexibility
- Individualization
- Systematization

Technical aspects of sustainability
- Compatibility
- Increase Quality
- Simplicity
- Optimize design

Another model, which is shown in the figure below, where all aspects are mixed, is to consider the building's entire lifecycle with a focus on the following core principles: "reducing resource consumption, reusing resources, using recyclable resources, protecting nature, eliminating toxins, applying lifecycle costing, and focusing on quality" (Kibert, 2005).

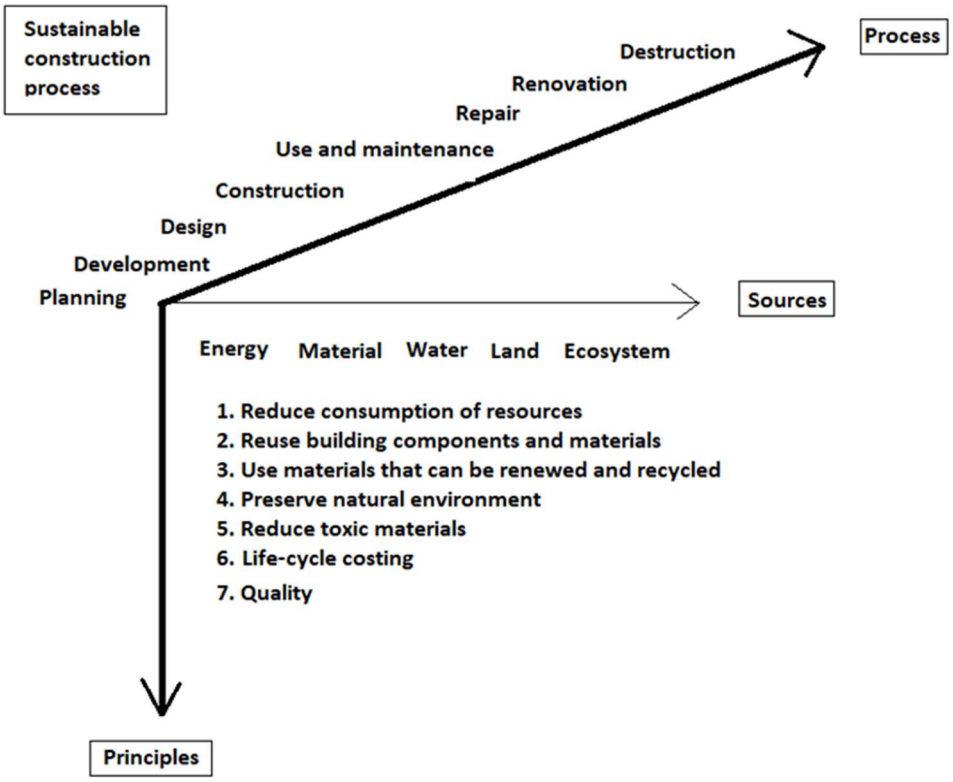

Figure 2.1 Sustainable construction process (Kibert, 2005)

As described above, different sustainability definitions and models, to adapt those into the construction industry in practice, have been developed. Common for all of them is the aim, namely, to reduce the construction industries' impact on the environment at the same time as the economic and social aspects are taken into consideration.

2.2 Different aspects of construction sustainability

Space efficiency

Space efficiency is part of the solution to achieve sustainability in the construction industry. "Improving space efficiency means to meet floor area needs without compromising or even increase land use" (Hauke, Kuhnhenne, Lawson and Veljkovic, 2016). Space efficiency is both about the use of land and the use of floor space. Multi-story buildings require less land than single-story buildings, and slimmer construction leads to more functional spaces. Space efficiency leads to financial benefits for the developer and owner, and by reducing heating and cooling, ventilation, and lighting, this will also benefit the environment.

Flexibility and building conversion

An important aspect of sustainability is a long-term perspective. This means that buildings should be constructed for today's needs and the future. Flexible and adaptability are key words that can lead to extending the life of a building, thereby reducing its environmental impact. It is advantageous if the building can be easily adapted to different users, for example, different office layouts, or those offices can be converted into apartments. If flexibility is foreseen during design, maintenance, and refurbishment activities, both time and costs are reduced.

Modular constructions consist of prefabricated volumetric components that are assembled on site, is a form of flexible constructions, that leads to faster construction times and reduced resources and waste. Another benefit is that these components easily

can be relocated and often adapted to different requirements. (Hauke, Kuhnhenne, Lawson and Veljkovic, 2016)

Design for deconstruction, reuse and recycling

Reuse and recycling contribute to increase the life of a material, and thereby lower its environmental impact. Reuse is the best solution for the environment, sometimes also for the economy, but in many cases, it is not possible, or at least not profitable, to do so. Then the recycling potential becomes of major importance. From a sustainable perspective, it is important to point out that there are different types of recycling. The best option is if the properties of the material can be improved or retained after recycling. The other option leads to lower levels of product quality with every recycling step. (Hauke, Kuhnhenne, Lawson and Veljkovic, 2016)

Being sustainable effective in architecture

Finally, sustainability is not only about effective design, reuse, and recycling the esthetic part is also of great importance. By focusing on design, the building will probably last longer and thereby reduce the environmental impact and costs. For example, a construction with a spectacular design will probably have a longer lifespan. (Hauke, Kuhnhenne, Lawson and Veljkovic, 2016)

2.3 Construction sustainability from a material perspective

To advance the goal of a sustainable construction industry, it is essential to address that construction materials have a significant impact on the result, especially now that energy conservation is quite optimized. Materials should not only fulfill the design requirements, the environment, economy, and society also need to be taken into consideration when making decisions. If different materials fulfill the same function, it is essential to consider factors such as, the extraction or manufacturing of the product, maintenance during the life cycle, durability, recyclability, and reuse.

A real threat, due to the extraction of elements, is the depletion of natural resources. This must be done with great caution and needs to be kept in mind when looking at the material perspective of sustainability. Manufacturing of materials, on the other hand, often results in the most significant emissions of CO_2 to the environment during a materials lifetime. A considerable amount of energy is required in the production, and where the energy comes from, affects the amount of emissions. Transportation, which is affected by the location of the fabrication and amount of material needed in the construction, is another factor that needs to be taken into consideration.

During the user stage of buildings, energy consumption partly depends on the building envelope. An ultimate solution that keeps the heat inside – and outside when needed will reduce the energy consumption, which in turn reduces the costs and the environmental impact. Maintenance of materials might be required, but another important aspect that also needs to be considered when talking about material sustainability is the change of use and utilization of areas. Materials that enable reconfiguration to meet future needs, so that buildings can be reconstructed instead of demolished, will be more favorable since this will minimize waste and use of natural resources. Materials must withstand stress both from regular use and expected changes in the climate without losing function or aesthetics. Durability, or lifespan, is of great importance. Increased population and migration to cities require area-efficient constructions, which can be achieved by utilizing different materials (Bygg21, 2018).

Finally, it is essential to consider what happens with the material after a building's end of life, since this is not necessarily when the material loses its capacity. It is beneficial

if the material can be demounted and reused, which might be the case for different components, such as beams, trusses, and columns. Effective recycling is another alternative, which partly aims to reduce the amount of waste going to landfills.
To achieve the goal of more sustainable materials, the development of low footprint manufacturing and material efficiency, which includes increased quality of materials, needs to continue. On the other hand, it is also a lot about how the materials are used and utilized. Today's pattern of construction, design, build, use, and destroy, can advantageously be replaced by a circular design that keeps products and materials in use, to achieve a more sustainable result and reduce waste. Material sustainability is then about maintenance and effective recycling and reuse of materials, which hopefully will favor both the environment and economy. As part of enabling a circular construction industry, it will be favorable to design for multiple life cycles, and a material's present sale value must be higher than the costs of restoring a material (Taylor et al., 2016).

2.4 Methods and standards for assessment of sustainability of construction

The Life Cycle Analysis (LCA) is a widely used methodology to include the environment in the assessment of sustainability. Factors such as scope, purpose, environmental categories (GWP – global warming potential, ODP – ozone depletion potential, and so on), and limitations can vary depending on approach and priorities, thereby affect how results can be interpreted and possibly compared. There are three main uses for LCA in the construction industry, namely, identify significant environmental aspects, improve environmental performance, and compare with others. Guidelines and calculation methods for LCA of buildings and building products are available in the standards SS-EN 15978: 201 and SS-EN 15804:2012 + A1:2013 respectively. LCA can be used to calculate a building or a product's environmental impact, preferably during its entire life cycle. An LCA can be divided into four Modules A to D, as shown in figure 2.2, whose signification are explained below (Boverket, 2019).

Module A, the construction stage, can be divided into two substages. The product stage, A1-A3, comprises the production, including everything from extraction of raw materials to transport, processing, and manufacturing, of the products in question. A4-A5, the construction process stage, covers transportation of the products to the construction site and the completion of the building.

Module B, covers the use stage, including the use, maintenance, repairs, replacement, refurbishment, and operation of the building. Energy and water use during operation, are examples of the latter.

Module C, the end of life stage, covers the processes required for demolition and transportation of the components for reuse, recycling, or disposal when the building has reached its service life.

Module D, benefits beyond the system boundary considering what happens with the products after the end of the building’s life, including reuse, recovery, and recycling potential.

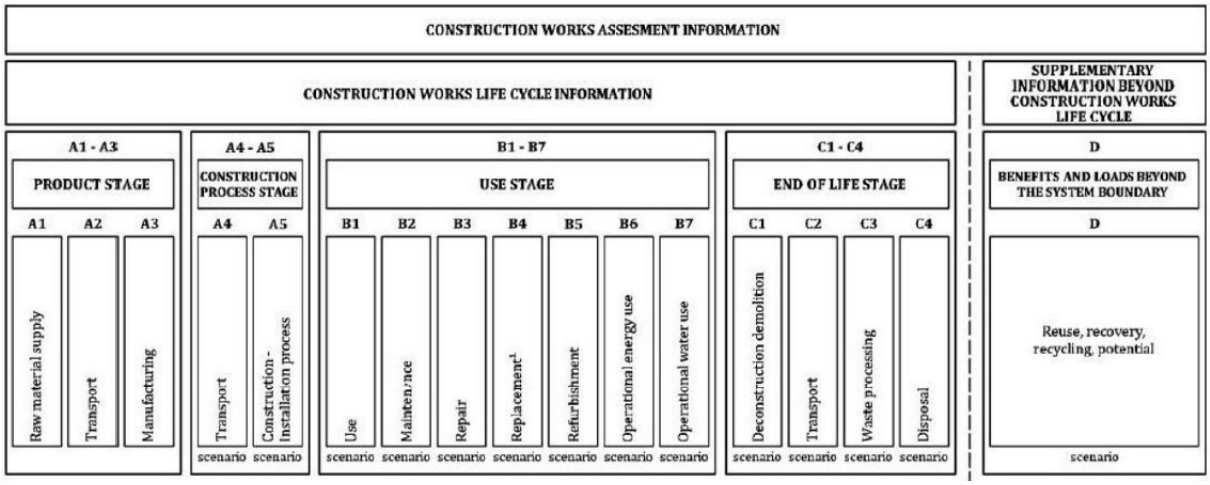

Figure 2.2 - Information modules for a life cycle analysis according to EN15804 (SIS 2019).

Life Cycle Costing (LCC), on the other hand, considers the economic aspect and is governed by the ISO 15686 standards. The main goal of LCC is investment efficiency. In the construction industry, this includes a comparison of different design alternatives based on initial, maintenance, and operational costs. In the same way as for LCA, LCC can also be done for the entire building or individual components. While LCA considers a product's entire life cycle (when used to its full extent), LCC values costs over a specified period (Gundes, 2016).

There are several challenges with the LCA and LCC, both separately and in an attempt to combine them. Depending on the approach, the requirements for data used in LCA vary. Sometimes it is sufficient to use generic (average) values, but if the result should reflect the building's actual environmental impact, product-specific data is needed. It can be time-consuming to do an LCA, and product-specific information is not always available.

Lack of data, this time concerning cost, is a problem that also is associated with LCC. Uncertainties in construction projects is one factor that makes it hard to predict future costs.

To get a more comprehensive sustainability assessment, it is essential to combine LCA and LCC. This can be of great importance for many stakeholders partly since the relevance of the use of LCA, without a thorough consideration of economic factors, might be limited in decision making. But even though it might be favorable, there are some challenges as follows in combining them (Gundes, 2016)

- The methods have different purposes and calculation rules, and the results are expressed in different units.
- LCA considers a product's entire lifecycle, while LCC accounts for the economic life of a project. Often, this only includes the costs that are relevant for the decision-maker.
- Data requirements, or inputs in the calculations, differs between the methods.

Some researchers (Gundes, 2016) suggest that this can be partly solved by expressing environmental costs in monetary units and then inserted in the LCC. Others conclude that a combination of the methods was not possible.

It might be possible to develop a standardized sustainability approach, which includes all three pillars of economic, environmental, and social aspects. Still, most important is

that the method becomes favorable in comparison with the alternatives that already exist.

3 Steel buildings

The steel used in the construction industry is an iron alloy containing 98% iron and a maximum of 2% carbon. Depending on the content of alloying, processing, heat- and surface treatment, steel properties, such as corrosion resistance, weldability, and strength, can vary widely. Standard steel grades covered in Eurocode are steel with strength class S235-700, i.e., steels with yield strengths 235-700 MPa. 50% of the produced steel is used in buildings and infrastructure, and by weight, it is the second most used construction material after cement (Jernkontoret, 2018).

3.1 Steel properties as a construction material

Steel fulfills several important functions in the construction industry today. It is a strong material relative to its weight. However, the steel itself is not resistant to fire or corrosion. Steel is needed as reinforcement in concrete structures, and it is not possible to build a timber structure without steel in the connections. There is a wide range of steel products with different application areas, some of them are listed below.

Plates and sheets

Steel plates, with varying sizes and properties used in the construction industry, are normally welded into columns, piles or beams with standard steel grade S355 or even S460. Plates with lengths up to 18 meters and widths up to 3.5 meters are available. In the building industry, thin steel sheets, typically 0.4 to 3.2 mm, are often used as non-loadbearing components, such as purlins, cladding products or light framing (Steel construction products, 2020).

Beams and Columns

Steel beams and columns are available in a wide range of standard open sections, such as IPE, HE and HL sections, and closed sections, e.g., circular, square, and rectangular, hollow sections. In the figures below, some examples are shown.

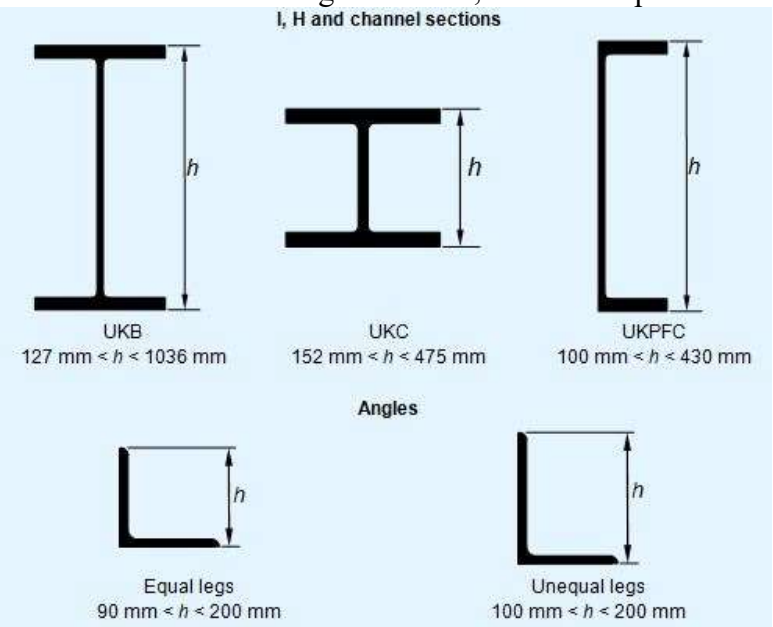

Figure 3.1 - Open steel sections (SteelConstruction.info, n.d.)

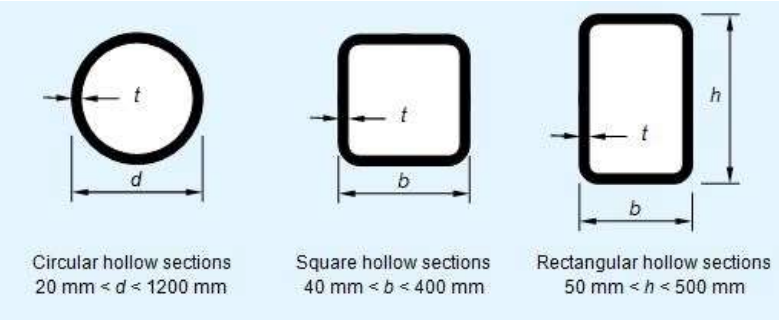

Figure 3.2 - Structural steel sections (SteelConstruction.info, n.d.)

Because steel itself is not fire-resistant, one solution is to fill the section with concrete, as shown in the figure below, and thereby comply with fire protection requirements.

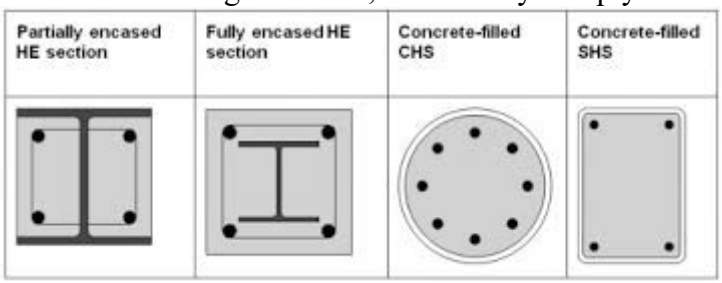

Figure 3.3 - Composite sections (SteelConstruction.info, n.d.)

Floor systems

A standard solution used in multistory buildings is a composite steel-concrete floor system. This is a lightweight construction that is largely prefabricated and thereby allows for fast construction times. There are mainly two different structural designs for this system, floor system with downstand beams as composite beams and slim floor systems with integrated beams, as shown below.

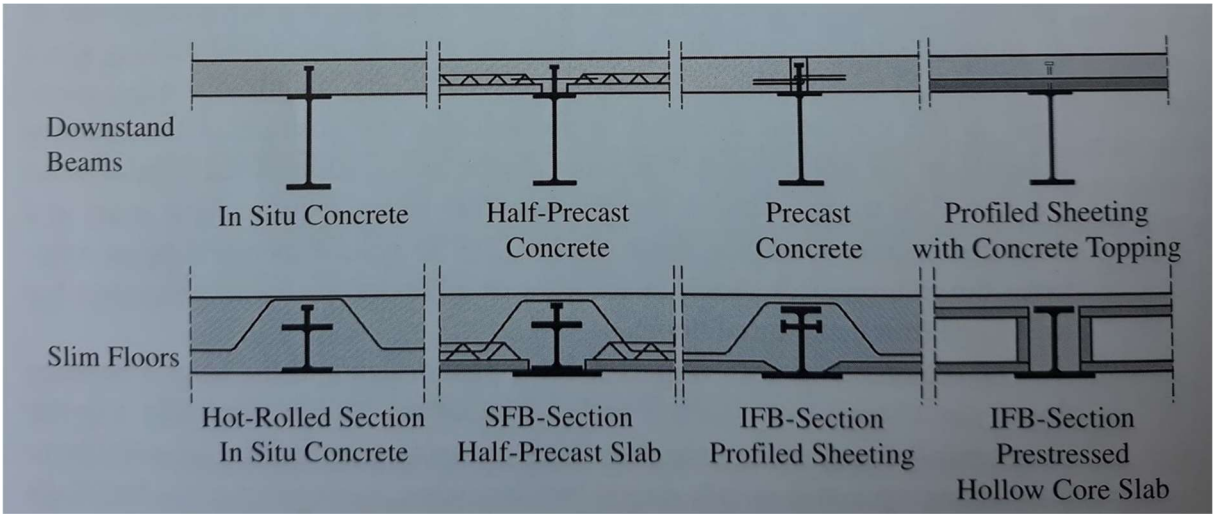

Figure 3.4 - Downstand and slim floor beams with different slab types (Hauke, Kuhnhenne, Lawson and Veljkovic, 2016)

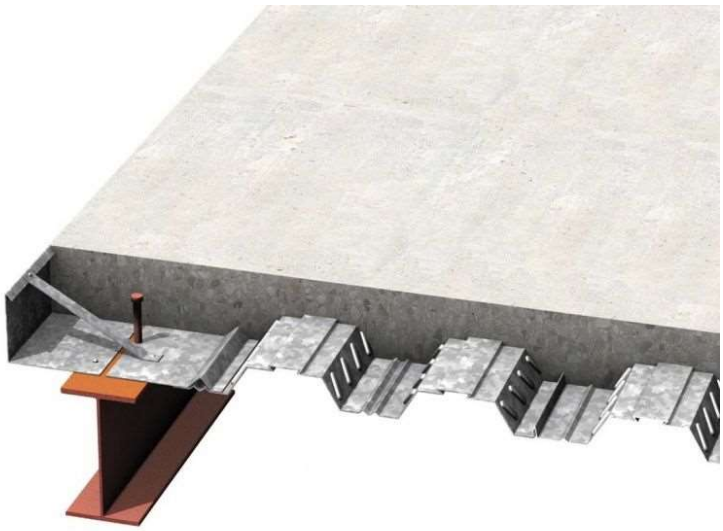

Figure 3.5- Slab with downstand beam (Welded stud, n.d.)

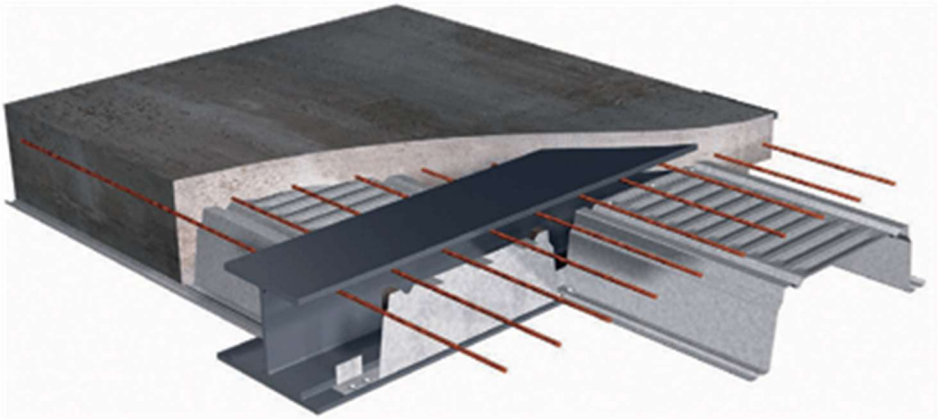

Figure 3.6 - Slim floor (architecturemagazine, 2013)

The first alternative allows for longer spans and is convenient if the use of internal columns should be minimized. Slim floors, on the other hand, are suitable for short to medium spans and reduce the story heights. (Steel construction products, 2020).

Building envelopes in steel (walls and roofing)

Lightweight steel sheets, in combination with insulation, are widely used to form the weathertight building envelope. The profiles of the coats vary, but they are all designed to channel water run-off. For aesthetic reasons, colored coating systems are offered. Two common forms of construction are sandwich designs, as shown below, and double-skin constructions. Both are cost-effective solutions, among other things, because the modular design allows for simple and fast mounting. 150 million m^2 of cladding, using steel sandwich systems, are approximately installed in Europe per year (Hauke, Kuhnhenne, Lawson and Veljkovic, 2016).

Figure 3.7- Sandwichpanel construction (Korea Puff, 2019)

3.2 Steel production technologies

The production of steel is very energy-intensive, and the main challenge for the steel industry is to reduce CO_2 - emissions from the production to lower the industry's impact on the environment.

There are mainly two ways of producing steel today, as shown in the figure below. The first, which accounts for approximately 70% of the world production (Grønnere – Stålproduksjon i dag, 2020), uses a blast furnace and a basic oxygen furnace to produce steel. This method uses iron ore, limestone and coal, and some scrap, as inputs. The second method uses an electric arc furnace to melt down scrap metal/steel scrape.

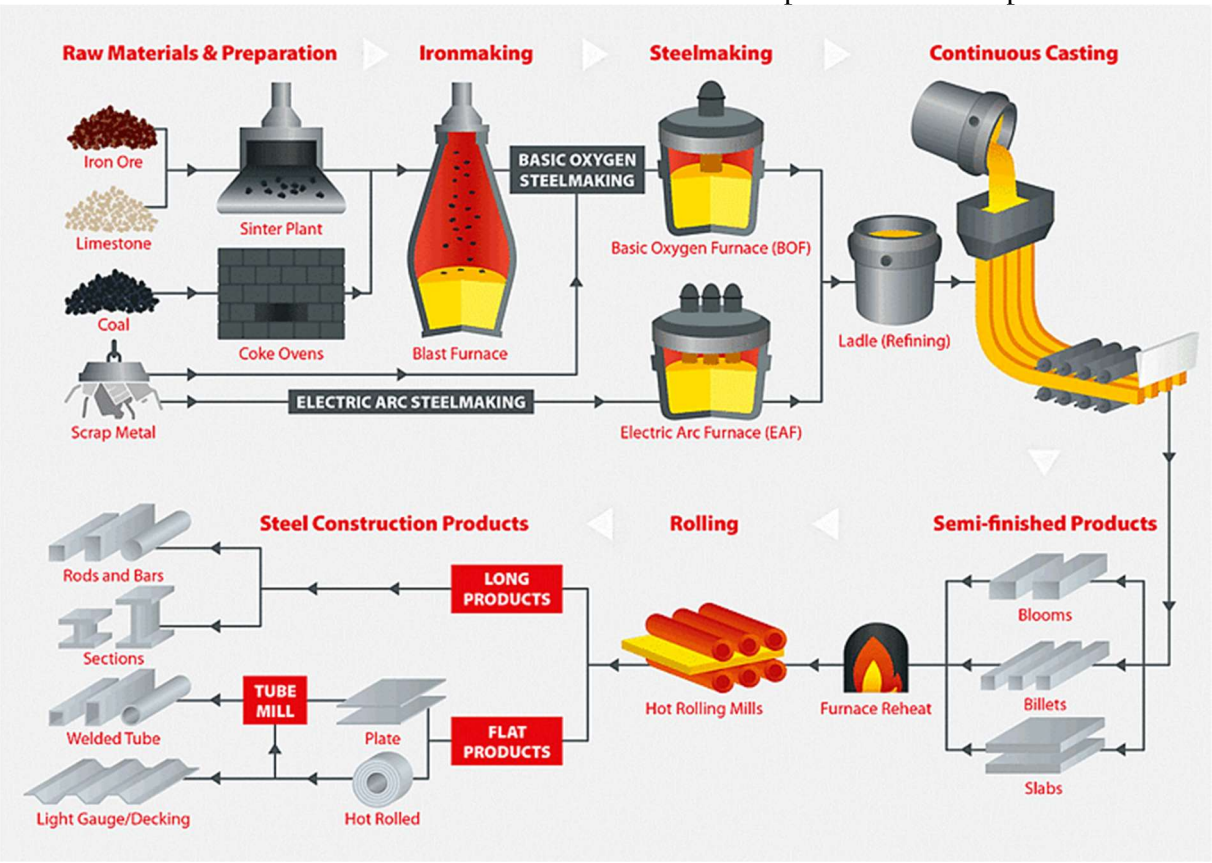

Figure 3.8 - Steel production (Nieto, 2019)

When the steel has been produced, chemical additives are added. Mechanical properties such as strength, ductility, toughness and weldability are affected by the content of alloy. The chemical composition must be carefully balanced, since small changes affect the result. The addition of certain substances may be beneficial for specific purposes

but may adversely affect other areas. One example is that manganese, niobium and vanadium can be added to increase the strength of the steel. On the other hand, this addition of alloys might have a negative impact on the weldability, for instance.
The next step is casting of semi-finished products, that finally will be rolled to desired steel products. Since steel is highly resistant to shaping when it is cold, it is generally rolled once it is hot. To make sure the steel is at the correct temperature for rolling (approximately 1280°C), it is feed into a furnish. Here it travels through several temperature control owns until it is at the correct temperature and ready for rolling. Whatever the product, the principles of hot rolling are the same. Steel is squeezed between rolls until the final thickness and shape are achieved. As shown in the figures below, the layout and the position of the rolls can vary (Steel construction products, 2020).

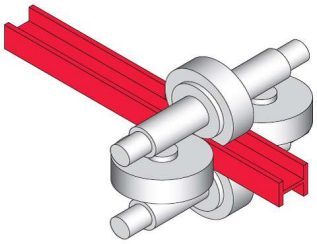

Figure 3.9 - Example of roll layout (SteelConstruction.info, n.d.)

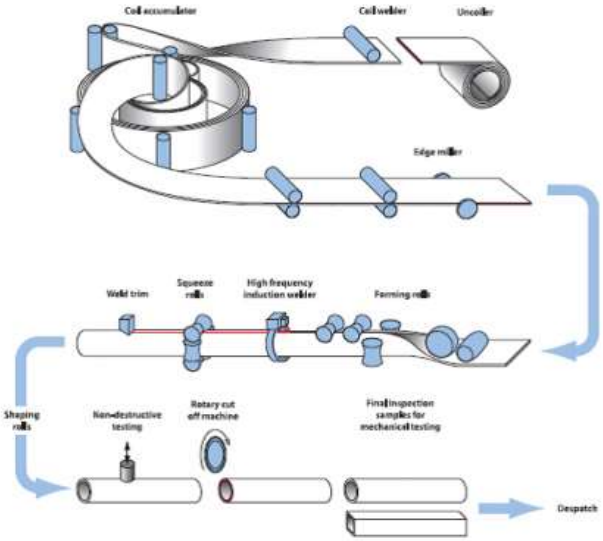

Figure 3.10 - Example of roll layout (SteelConstruction.info, n.d.)

Almost all waste from the steel production is utilized today. Slag can, for instance, be used in road construction and exhaust gases can be used in electricity production. This is beneficial to the environment, compared to just being dumped.
Although the two manufacturing methods may seem quite similar, the difference in environmental impact is significant. Scrap-based production uses on average, 60% less energy and emits approximately 70% less CO_2 compared to the production based on iron ore (Grønnere – Stålproduksjon i dag, 2020).
According to Statista, the supply of iron ore will not be a limitation in the future, iron is the world's fourth most common element. Steel scrap, on the other hand, is a limited

resource, which is one of the reasons why it only accounts for 30% of the production today. Until scrap can cover the need for steel, the production of iron-based steel, as well as the development of this method, needs to continue to reduce the emissions.
There are now two ongoing projects, one focusing on fossil-free production, led by SSAB (Först med fossilfritt stål, 2020), and the other is about finding a solution to capture and store CO_2, led by SINTEF and NTNU (CO2 - Storage - SINTEF, 2020). If these projects succeed, the steel industry will be able to reduce its environmental impact further.

3.3 Sustainability assessment of steel buildings

From a sustainable perspective, there are mainly three concerns that are highlighted when talking about steel. The production of steel, as mention earlier, fire, and corrosion. At high temperatures, steel loses its strength, and therefore fire protection is often needed. Structural fire protection or fire sprinkler system can, in some cases, solve the problem. Fire retardant paint is a third solution, but this alternative might include chemicals that affect the environment negatively and should, therefore, be discussed. If it is intended that the steel should be exposed to water, which is the case for outdoor constructions, for example, corrosion is something that you must be aware of. The most common methods that are used to overcome the problem today are rust protective coating and hot galvanizing. Anti-corrosion agents might also harm the environment.

Space efficiency

Steel enables large spans and column-free spaces due to its strength to weight ratio. In single-story buildings, clear spans of over 50 meters can be achieved, and by using trusses or lattice construction, this can be extended to 150 meters (Hauke, Kuhnhenne, Lawson and Veljkovic, 2016). Since service systems can be integrated into the structural zones, the floor-to-floor heights can be reduced, and the space efficiency is increased even further.

Flexibility and building conversion

As mention above, steel allows for column-free areas and thereby flexibility in design. The floor plan can be easily adjusted to new requirements through installations or removal of internal lightweight partitions. Bolted joints also favor reconstruction.
Steel structures can facilitate maintenance and changes during the user stage. An example is that ventilation ducts can pass through steel trusses. In this way, the installations are easily accessible, which facilitates maintenance and possible replacements. Considering modularity, sandwich elements are examples of steel designs already in use.

Design for deconstruction, reuse and recycling

If the entire life cycle is considered (alt. from a life cycle perspective), steel has a clear advantage; namely, it is a so-called circular material. Once the steel has been produced, it is a permanent resource. Steel can be recycled an infinite amount of times without loss of strength. It can be melted down into new products, with the same or even better properties than the former. Steel components from building constructions can be easily disassembled and reused. 99% of the steel used in the construction industry is recycled or reused (Steel, sustainability and the circular economy - Building Products, 2020).
The need for maintenance is usually low, and the properties of steel are normally unchanged unless the element is exposed to fire or fatigue. This means that steel has a long service life, and that the costs and environmental impacts can be spread over many years.

Being sustainable effective in architecture

Steel can be formed into a wide range of products with different shapes, surfaces, and properties, which allows for freedom in design, and thereby, form and structure of buildings can vary widely. Due to properties that enable lightness in combination with high loadbearing capacity, elegant and spectacular steel constructions have been designed. Mies van der Rohe's "Crown Hall", Frei Otto's cable structure at Montreal Expo 1967 and D2 Tower in Paris by Anthony Béchu, in association with Tom Sheehan, are three examples of that, all shown below.

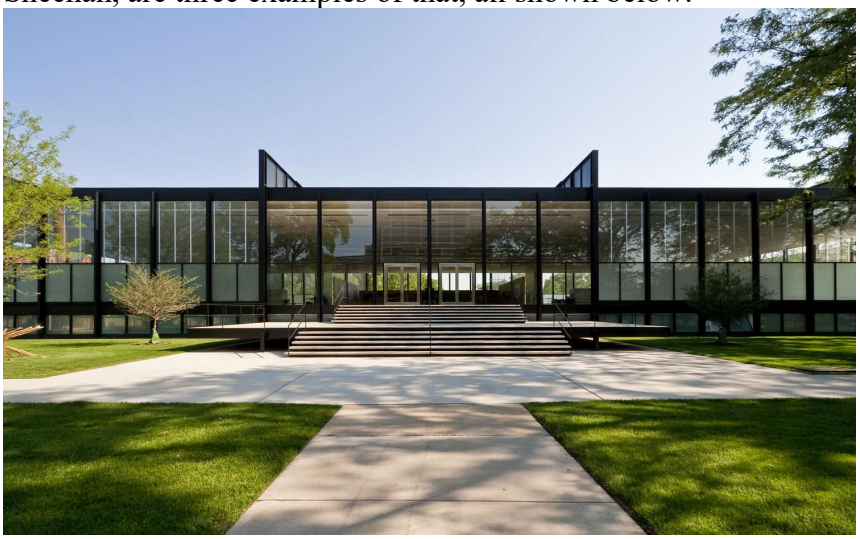

Figure 3.71 - Crown Hall (Umstead, n.d.)

Figure 3.82 - Frei Otto's cable structure (Pinterest, 2008)

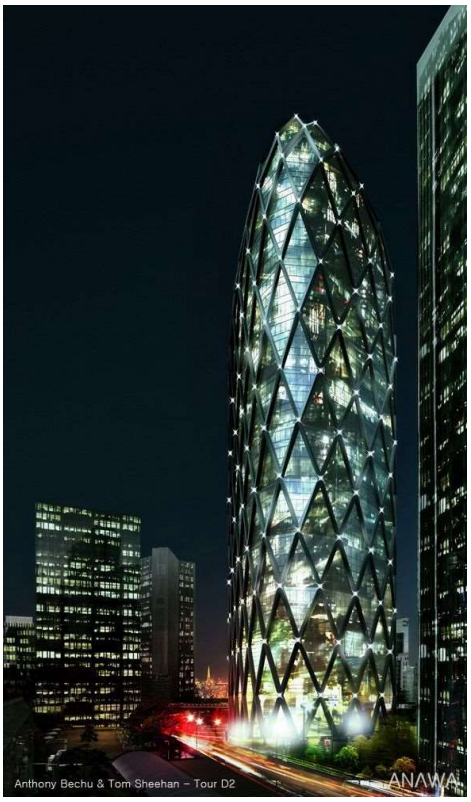

Figure 3.93 - D2 Tower in Paris (Pinterest, n.d.)

Steel is often associated with fast construction time and a "dry" building site. This, in combination with its lightness and performance, "makes steel a sustainable material with great potential for the future" (Hauke, Kuhnhenne, Lawson and Veljkovic, 2016). In the report "Sustainability assessment framework for low rise commercial buildings," various design alternatives for a low rise commercial building construction were compared by using Multi-criteria decision methods, MCDM. This is a method that is used to find the most sustainable construction solution. Steel was included in both the solution with the lowest environmental impact (a steel–wood system), and the most economical one (a concrete–steel system). This report substantiates that steel can contribute to sustainable solutions (Sadiq et al., 2016).

3.4 Steel in comparison to other construction materials

The production of steel generates more CO_2/kg than the production of both concrete and timber. On the other hand, steel is the most recycled material in the world. After recycling the properties of steel reminds, which means that a steel beam, for example, can be fused to a new steel beam. Timber and concrete, however, can only be used as secondary materials after recycling, for example, as chipboard or as ballast in new concrete. Steel can even be upcycled, which means that it can get higher strength properties after recycling. Whereas timber and concrete only can be downcycled, they lose strength for every step of recycling.

Unlike timber, steel is an inorganic material that is not susceptible to rot, termites, or mold. When designing for timber, the fact that the mechanical properties vary depending on moisture content and time must be taken into account. If the load is kept constant, a timber beam will bend down more and more over time, timber creeps. (Svenskt trä 2015). This is not the case for steel, which from that perspective makes it more durable. The depths of the timber beams are approximately twice that of steel

beams, which makes steel more space-efficient (Hauke, Kuhnhenne, Lawson and Veljkovic, 2016)
In comparison to concrete, steel is a light material, which means reduced requirements on the foundation. Unlike concrete, steel is a so-called dry material, which implies more predictable construction times. On the other hand, concrete offers advantages when it comes to fire, and meets the requirements for the highest fire classification (Svensk betong 2020). When considering effective use of space, a classic steel column requires 75% less floor space than an equivalent concrete column (Hauke, Kuhnhenne, Lawson and Veljkovic, 2016).
In comparison to brick walls, steel offers thinner construction solutions, partly due to the properties of modern lightweight cladding.

3.5 Advantages of steel

- Due to its low weight, steel offers advantages in transportation and erection, as well as reduced requirements at the foundation compared to concrete. It is easy to perform renovations, and extensions can easily be made on top of existing buildings without overloading the foundation.
- With the strength-weight ratio in mind, steel is a strong material that enables for large spans and free surfaces. High strength steel makes it possible to increase the load on the structures even further.
- Allows for flexibility and freedom in design due to its strength and a wide range of products with different shapes and properties.
- A long service life due to low maintenance and advantages when it comes to the changed use of buildings means that the costs and environmental impacts can be spread over many years. Steel is an inorganic material, which means that it is not susceptible to biological degradation.
- Steel is a circular material. It can be recycled repeatedly without loss of quality, upcycled (get higher strength after recycled), and reused. Steel is the most recycled material in the world today, and about 75% of all steel manufactured is still in use. (Jernkontoret, 2018)
- Corrosion is something that you must be aware of if it is intended that the steel should be exposed to water, which is the case for outdoor constructions, for example. The most common methods today are rust protective coating and hot galvanizing. Different grades of stainless is also available and a solution for corrosion.

3.6 Examples of steel contribution to sustainable solutions

Below, examples of how steel can contribute to a circular building industry, and how the choice of steel grade can have an impact on the environment, are listed.

3.6.1 Reuse of steel

As part of achieving a circular construction industry, the reuse of materials will be significant. Steel is a material with great potential in that area since the properties of steel products in a worn-out structure are normally unchanged unless they are exposed to fire, corrosion or fatigue. It is important to be able to ensure that the reused material meets the performance requirements required for use in structural design, according to EN1993. The relevant material properties need to be known and documented, but if some documentation is missing, there are testing methods available that ensure the quality. As a benchmark, it is recommended that all members to be reused should come

from a building structured after 1970, then the material properties are similar to the ones we use today (Widenoja, Myhre & Kilvær 2018).
Constructive measures, including increased use of screw joints, and expanded documentation and storage of component properties using BIM, will facilitate future reuse. A change in the design culture will be beneficial. By planning for two building steps, which means that it is decided what the construction will be used for after it is demounted, and build structures that are easy to mount and dismantled, it will be easier to reuse the construction later on.
Since it is not common to reuse building structures in Sweden today, some examples, showing that it is possible, are listed below:

9 Cambridge Avenue, England, 2015, is a reuse project where a warehouse had to be removed to make place for the Leigh Road bridge. Among other things, the steel frame was dismantled and rebuilt elsewhere on the Estate. Studies show that this resulted in 56% lower emissions of CO2e compared to new construction, and 25% lower costs. (Segro 2016)

Figure 3.104 Internal view of the warehouse (SteelConstruction.info, n.d.)

The bus terminal in Schiphol, the Netherlands 2013, is an example of a steel construction that has been reused several times. First, it was used as a Spitfire hangar outside London in 1942. It was moved to Rotterdam in 1958, where it served as a hangar at Zestienhoven Airport until 2013, and now, after some reconstruction, it stands as a bus terminal at Schiphol airport in the Netherlands. Screws have been used in all connections, something that has facilitated the reuse. In 2015, the building won an award for innovation in sustainability (Widenoja, Myhre & Kilvær 2018).

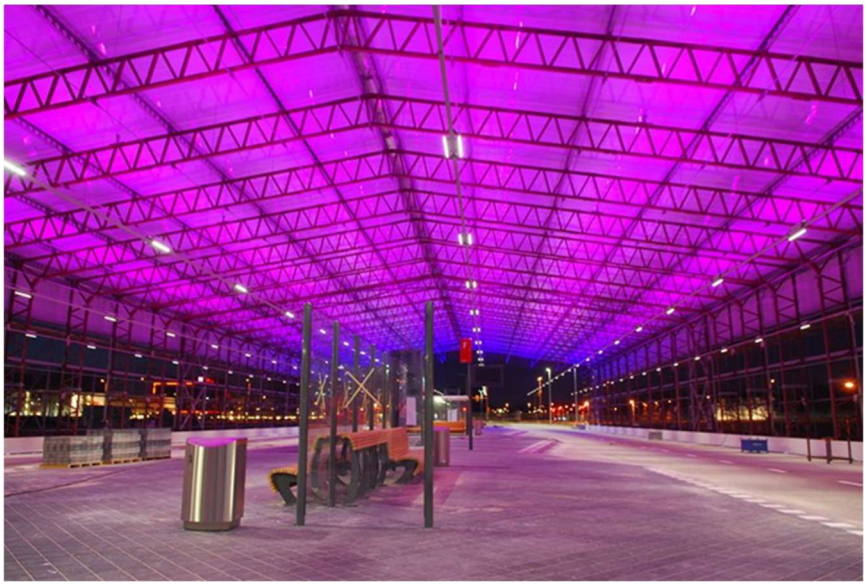

Figure 3.115 The bus terminal in Schiphol (Bushangar, n.d.)

Constructions used for The Olympic Games in London, 2012, where the organizers had a goal to be sustainable, a lot of steel was used. The basketball arena was designed for temporary use. Steel construction enabled fast assembly time and a light structure, and the entire arena was dismantled after the games. The roof construction at the Olympic Stadium was built with surplus stock of gas pipes that otherwise would have been melted down. Around 10,000 tonnes of steel were used in the Olympic Stadium, which by weight is quite little (Widenoja, Myhre & Kilvær 2018).

Figure 3.126 The Olympic Stadium in London

3.6.2 High strength steel

To point out that there are differences between steel grades, in terms of economy and environment, a case study of Friends Arena is a good example. The use of high strength steel instead of standard steel grades can contribute to reduce the environmental impact, as shown in table 3.1, since less material is needed in the construction.

Figure 3.137 Friends Arena in Stockholm

High-strength steel was used in the ceiling at Friends Arena in Stockholm, and by replacing 32% of the standard steel grade, S355, with high strength steel, the weight could be reduced by 13 %. The weight was decreased from 4 584 to 4 000 tonnes. This resulted in an economic saving of approximately 20 000 000 SEK and a reduction of 900 CO2e (Jernkontoret 2015).

Table 3.1 Weight, weight reduction and reduced greenhouse gas emissions (Jernkontoret 2015)

	Roof weight [tonnes]	Weight reduction [%]	Weight reduction upgraded parts [%]	Reduced emissions [tonnes CO_{2e}]	Reduced energy used [MWh]
Reference arena 100 % S355	4 584	-	-	-	-
Friends Arena	4 000	13	21	900	3 600
Arena with 54 % high strength steel	3 852	16	28	1 000	4 000

4 Interviews

The purpose of the interviews was to get an overview of how different actors in the construction industry work with sustainability today and in what situations and for what reasons steel is chosen as construction material. 21 people have been interviewed, 7 Structural Engineers, 4 architects, 7 environmental and sustainability experts, and 3 others working in the construction industry. The results are divided into four sections below.

4.1 LCA and Environmental assessment methods

Environmental grading schemes are widely used in various contexts today, and the LCA method can be applied in different ways. If the construction industry should be able to compare different results and find out which alternative that has the lowest impact on the environment, a consistent application of LCA is needed. So, to find out whether there is a standard method or not, interviews were conducted.

	Architect			Structural engineers			Sustaina-bility experts		
	Yes	No	Depends	Yes	No	Depends	Yes	No	Depends
Is it common to certify buildings today?	3			2			5		
Do you work with LCA to compare different materials?	2	2			7		6	1	
Is the entire lifecycle considered when comparing different materials?		2	1		7			3	4
Is there a standard method that is used to calculate the environmental impact of construction materials today?		4			7			7	

	Others			Persons who did not answer the question
	Yes	No	Depends	
Is it common to certify buildings today?	1			10
Do you work with LCA to compare different materials?		2		1

Is the entire lifecycle considered when comparing different materials?		2		2
Is there a standard method that is used to calculate the environmental impact of construction materials today?		3		

4.1.1 Excerpts/comments from interviews

Environmental grading schemes are widely used in the building industry today, BREEAM, LEED and Miljöbyggnad are some of them. They have increased the environmental focus and contributed to more sustainable buildings, by including many environmental aspects. One negative point is that there is room for sub-optimization of buildings, and god solutions may have been excluded to achieve better ratings. Times spent on administration work could have been used differently and maybe benefited the environment more.

LCA is often used in conjunction with environmental assessment methods but is not involved in every project. Some of the interviewed persons never work with LCA. Others stated that the company take the help of consultants if the client requires some kind of certification, and some work with the method themselves. So, the knowledge about the method varies. Often it is only module A that is taken into consideration. Neither of the interviewed persons includes all Modules A to D when they use LCA. Still, several of them think that it is vital to consider the entire life cycle to be able to state which solution is best from an environmental perspective. "If you say that timber always has the lowest impact on the environment, then you have not considered the entire life cycle." It can be quite extensive and time-consuming to do an LCA, and a lot of data that are required are often missing today. It is time-consuming and thereby often expensive.

One of the environmental experts says that if it should be possible to prove or to compare different results, a standard method is needed. She says that there are companies that state that they have built climate-neutral buildings, but from her point of view, that is impossible today. It is easy to indicate that something is sustainable or have a low environmental impact, but it is hard to prove.

It will take a lot of time and effort to build a functioning digital system, but when the system is developed, it will be easier to use the LCA method. The climate problems will not be solved within the next few years, so it is essential to look in long terms, and consider the entire lifecycle.

4.2 Sustainability

To find out if there are cases where steel is the most sustainable solution, people in the construction industry were asked which factors they think affects whether a material or solution is sustainable or not.

	Architect			Structural engineers			Sustaina-bility experts		
	Yes	No	Depends	Yes	No	Depends	Yes	No	Depends
Is the environmental impact considered when choosing constructions material?	3	1			6	1	3		4
Do you think that the construction material is of significant importance to the overall environmental impact of a building?	3	1		2	1		7		
Is the client of significant importance when it comes to sustainability?	4			4			6		
Do you think that construction material should be chosen based on function?	1	2		7			5		
Do you think that timber is the most sustainable material?	2	2			7		1	6	

	Others			Persons who did not answer the question
	Yes	No	Depends	
Is the environmental impact considered when choosing constructions material?		2		1
Do you think that the construction material is of significant importance to the overall environmental impact of a building?	2			5
Is the client of significant importance when it comes to sustainability?	1			6
Do you think that construction material should be chosen based on function?	3			3
Do you think that timber is the most sustainable material?		3		

4.2.1 Excerpts/comments from interviews

"Sustainability is about uniting Function, Economy, Beauty (=skönhet in Swedish) (the beautiful is sustainable, the other we tear), Technology to a whole FEST (=party)."

Time, circular materials and economy, function, maintenance, consumption, lifecycle perspective, and production are words mentioned in conjunction with sustainability. According to the majority of those interviewed, time and function are the most important ones.
Time, the lifespan of the building. Some states that timber is the most sustainable material, independent of time. Other states that timber is an organic material that changes over time, and partly due to moisture problems, it will have a shorter lifetime than steel, for instance. The problem today is that there are often short operating times, meaning that the capacity of the materials is not used to its full extend. In the future, it becomes important to preserve existing buildings instead of demolishing them and construct buildings that are easily assembled and to demount. In that way, we also enable for reuse of materials which contribute to circularity.

Function, what should be achieved. Based on that, different solutions and how you can optimize them can be considered. The climate issue is a part of it, but several aspects need to be considered".
It is vital with a holistic perspective and consider every aspect, and it is essential with the right material at the right place.

4.3 Economy and environment

The economy is of great importance in all industries, but to find out how important it is compared to the environment, and if customers are willing to pay a little extra for a sustainable alternative, the interviewed persons were asked, among other things, the questions below.

	Architect			Structural engineers			Sustaina-bility experts		
	Yes	No	Depends	Yes	No	Depends	Yes	No	Depends
Does environmental assessment methods lead to increased sales value?	2	1		2			4		1
Is the client often willing to pay more for the environment?	2	1	1			4	2		4
Are economic interests a priority over the environment?	4			7			6	1	
Is there a need for incentives and requirements to reach the climate goals?	3			4			6		
Do you think it is good with mandatory reporting of climate declarations for new buildings?	1		1	2			3		2

	Others			Persons who did not answer the question
	Yes	No	Depends	
Does environmental assessment methods lead to increased sales value?				11
Is the client often willing to pay more for the environment?			1	6
Are economic interests a priority over the environment?	3			
Is there a need for incentives and requirements to reach the climate goals?	3			5
Do you think it is good with mandatory reporting of climate declarations for new buildings?	1		1	10

4.3.1 Excerpts/comments from interviews

Many clients, both private persons and companies, are willing to pay some extra for the environment if they are capable of it. More people begin to realize that it is profitable to invest in the environment, and often it is also the driving force for them to do so. There are huge variations between different companies and clients when it comes to the environment. Some companies have their own environment and sustainability departments, while others only have individual persons working on these issues. One environment expert says that "today everyone knows that CO_2-emissions has a negative impact on the environment, but few knows methane contributes more to the greenhouse effect than a corresponding amount of CO_2". To reach climate neutrality 2045, there is a need for incentives so that everyone can keep up, and requirements so everyone must do so. Boverket has submitted a proposal for mandatory reporting of climate declaration for all new buildings in 2022, where module A1-A5 should be mandatory to declare. Someone says that it is positive that it is a good beginning, and it would be too much work if all modules A to D should be included. They also point out that there are already other instruments that focus on other parts. Others are more skeptical and state that there is no point in declaring if there are no limit values or requirements to improve, then it only becomes extra paperwork. It is a risk for sub-optimization, and the entire life cycle is not considered.

There are municipalities, Växjö, for instance, that earlier had timber building strategies, meaning that they want to build in timber to reduce the environmental impact. They have now changed policy and states that they want to reduce the environmental impact, regardless of material.

"While steel and concrete have received a reputation for having a negative impact on the environment, many claims that wood is expensive."

It is more expensive to produce high strength steel than standard steel grades, but it can be beneficial for the environment. That is also the case if we compare steel produced in Sweden with steel imported from China. It is important to point out that the GWP value for steel varies widely, depending on where and how it is produced. If the steel is manufactured in China, this value is almost double compared to production in Europe. By using steel scrap instead of iron ore, the GWP value is suddenly down to about 0.5 kg CO2/kg, which is 1/10 of the steel from China. So, it is a big difference between steel and steel. Utilize the iron ore for higher steel grades, and steel scrape for other purposes as it will be challenging to satisfy the market with scrap alone.

4.4 Steel

Some of the properties of steel are well documented, but to find out when it is preferable to use steel and in what situations it is chosen, persons in the construction industry were asked about their opinions.

	Architect			Structural engineers			Sustaina-bility experts		
	Yes	No	Depends	Yes	No	Depends	Yes	No	Depends
Is steel a first choice for industrial halls?	4			5			1		
Have you been involved in projects where steel has been reused?		4			7			6	
Would you say that the reduced environmental impact of recycled steel makes up for increased handling?	1			1		3			1

	Others			Persons who did not answer the question
	Yes	No	Depends	
Is steel a first choice for industrial halls?	1			10
Have you been involved in projects where steel has been reused?		3		1

Would you say that the reduced environmental impact of recycled steel makes up for increased handling?	1			14

4.4.1 Excerpts/comments from interviews

Steel fulfills several important functions in the construction industry today. It is needed both as reinforcement in concrete, and it is not possible to build a timber structure without steel in the connections, for example. "Steel has unique strength properties which allows for slim constructions and large spans." If the risk of explosion needs to be considered, steel is superior. It is well suited for change of use, reconstruction, and extensions. This helps to ensure that buildings can be preserved for long periods. Timber and steel have similar properties, but a disadvantage with timber is that it is an organic material whose properties are affected by the climate. So, in some cases, it is more favorable to use steel. There are also cases where steel is a much cheaper alternative.

Below some comments, about advantageous of steel, from the interviews are listed

- Steel is the best choice if you want slim constructions
- Steel allows for a light weighted frame, which leads to reduced load on the slab and less material consumption. This is advantageous for both the environment and the economy
- Steel is a material with fantastic properties. The main advantage is that it has the strength properties it has, strong in tension and compression, allows for freedom in design, relative slim constructions despite large span
- Steel is a so-called "dry material," which leads to shorter, more predictable construction times compared to concrete
- If there are height regulations in the detailed development plan, steel is a better alternative than timber in terms of profitability. Due to smaller dimensions, several floors can be built by using steel.
- Generally, only half the height of a timber beam is needed if you choose steel instead
- Steel is usually the best option for extension
- Very efficient to use steel where there are large spans and huge loads
- Steel, in combination with concrete, is advantageous to use in hospital buildings.
- Steel has a vital function in everything in the construction industry. It has excellent properties and is an efficient material.
- I think that a concrete core in combination with steel columns is often the best solution for tall buildings with several floors.
- Steel can be used as stabilization in the façade
- What makes steel sustainable is that it has a long service life. If it is designed correctly, has the right surface treatment, and so on, then it can last forever. It is flexible; you can rebuild, expand, and strengthen the building.
- Steel is a circular material that can be recycled repeatedly. It can be upgraded after recycling, get higher strength properties, which in turn leads to less steel per component. It can also be reused.

- A report made by Ramboll in 2012 shows that timber buildings are 30% more expensive than steel and concrete structures.
- We got one example, in 2019, on a grocery store where both a steel and timber construction were evaluated. It turned out that it would cost 22 000 000 NOK and 30 000 000 NOK respectively
- Steel can be chosen from a sustainable perspective
- From the beginning, the cultural center in Skellefteå was meant to be a timber project, but since timber creep and a whole floor would have been needed to carry the loads, they chose to use steel as well.
- I think that steel always will be needed in the industry sector, where we have to deal with heavy loads. Lattice trusses of steel that allows for large spans are irreplaceable.
- Most of the industry halls that we draw are very simple. There are already finished building systems of steel and sandwich elements that are very affordable and difficult to compete with. In that case timber is more expensive
- If you want very slim, slender structures in columns and beams, it is favorably to use steel. Steel trusses are good solutions if installations should pass through the construction. It can also be chosen for aesthetic reasons
- Steel probably has more significant advantages when it comes to public buildings such as offices, with slightly higher demands on flexibility and spans for instance
- Steel is irreplaceable in the industry due to the heavy loads. I also work with a housing project offshore, where the risk of explosion needs to be taken into consideration. In that case, steel is also a given material.
- Curtain walls with sheet metal studs is a very competitive solution. Steel facilitates if you want openings in the structure.
- Use of steel structures facilitates the installers
- In India, steel temples are built to last over 1000 years. With that time perspective in mind, steel is superior to concrete and wood
- I think that steel is chosen in industry halls due to its properties. Compared to timber, it is more durable, steel takes more load, and it is more predictable. Traditionally, steel has been superior in industry halls.
- If the material has not been damaged during the construction period, both timber and steel can be reused. But it is hard to make sure that the building is dense during several years and then steel has an advantage
- We need to reduce the CO_2-emissions. In that way, wood is a good alternative, but you cannot solve everything by using timber. It is an organic material, and moisture requirements can be challenging to fulfill.

Office building, industry halls, and grocery stores are examples of structures that require large open spaces, and it is often advantageous to use steel. In buildings used for different industries, where steel is used to carry heavy loads or explosion needs to be considered, it is often irreplaceable.

Due to fire and corrosion, using steel can be a challenge. Cowi has an ongoing project in Gothenburg where they wanted small dimensions, so by using galvanized outdoor steel columns filled with concrete; they solved the problems.
Neither of the persons that were interviewed have been involved in projects where steel has been reused, and they do not decide where the steel comes from.

Some of the structural engineers, do not think it is a good idea, pointing out that there is no system for reuse in Sweden, a lot of work will be required, and it will be challenging to ensure the quality.
On the other hand, some see this as a permanent solution to the climate issue. Even if it requires extra work, it will be worth it. Examples show that it is possible and there are solutions to the problems mentioned above. "By thinking easily mountable / easily demountable, especially in steel and timber, there are great opportunities for reuse. Crystal Palace, a large steel and glass building that was built in London 1851, is a great example of that".

5 Discussion

Sustainability is highly relevant today, and there are divided opinions about which material is the most sustainable in the construction industry. Some of the aspects conducted in the literature studies and the interviews are discussed below.

5.1 LCA and environmental assessment methods

Both literature studies and interviews show that there is no consistent application of LCA in the construction industry today. There may be several reasons for this. On the one hand, it can be quite extensive to do an LCA, it requires a lot of work, and thus an additional cost that companies may not be willing to pay. Or lack of expertise, with knowledge of the method, available. On the other hand, it can be challenging to agree on boundaries, what should be included and what can be excluded.

5.2 Sustainability

In the interviews that were conducted, it was an agreement that time and function are two factors of main importance for a sustainable solution, and which material that is most sustainable depends on the situations, which is also shown in the literature. Three people that were interviewed announced a different opinion by stating that timber is the most sustainable material.
One the one hand, if a short time perspective is considered and CO_2-emissions from the production of the materials are of significant importance, which might be the case if the building is demolished after 30 years, timber might be the most sustainable solution. On the other hand, if a longer time perspective, 200 years, for example, is considered and emissions from the production are of less importance, that may not be the case.
For 200 years, it will be relevant to include recycling and reuse. Both timber and steel can be recycled, but only steel can be upcycled. It can be recycled repeatedly without loss of strength.
Steel offers advantages when it comes to change of use, extensions, and reuse.
So, considering a more extended period, maybe steel is a more sustainable option.

When it comes to function, several different cases need to be considered. On the one hand, if a two-story residential building is considered, timber might be the best solution. On the other hand, if the risk of explosion needs to be considered or a swimming pool should be built, that is not the case.

While space efficiency is mentioned as an aspect of sustainability in literature, this is not emphasized in any of the interviews.
On the one hand, this may be due to the fact that there has recently been a great focus on the environment and production of materials when talking about sustainability, and since it is such a broad concept, it is difficult to include all aspects during an interview. Or it may be because the people interviewed do not think of surface efficiency as an aspect of sustainability. On the other hand, when we talked about steel, slim constructions were mentioned as an advantage, which may indicate that some people had space efficiency in mind.

5.3 Economy and environment

There is an agreement, with one exception, that economic interests are a priority over the environment after basic requirements on the environment are met. One person stats that economics and the environment are given equal priority at their company today. There might be several reasons for that. Some thoughts are that the company has realized that there are financial benefits in investing in the environment. It is a high environmental focus in many of their clients' projects or that they are at the forefront and take responsibility for reaching the goal of climate neutrality in 2045. But I do not think that any company wants to be involved in a climate-neutral building project if the client told them that you would not be able to earn money.

There is a need for incentives and requirements to reach the climate goals, but the question is of what kind. Climate change is happening faster than expected, so maybe the only alternative is to impose super strict requirements already in the procurement of projects. Only companies that can fulfill these requirements can receive the project, and those how cannot, will not survive in the future. One the on hand that forces everyone to focus on the environment. On the other hand, it can become unmanageable for some companies, which means that they cannot continue their business.

Boverket, the National Board of Housing, has produced a proposal for mandatory reporting of environmental declarations for new buildings in 2022, where module A1-A5 is mandatory. On the one hand, this can be a good start. Module A is almost always included when people are working with LCA, so for them, it will not lead to much extra work in comparison to today. It will probably be more manageable to start with only one module for those who never has used the method before. The CO_2-emissions from the production needs to be lowered, and there are no restrictions on that area today. If it becomes mandatory to declare module B to D later, it will be easier to follow. On the other hand, a problem with eliminating the other modules is that the entire lifecycle is not taken into consideration, which means that you do not get a fair estimation. Module A will show that timber is the best solution for the environment today, but from a holistic perspective, that might not be the case. Declaration, without limits or requirements, will only lead to extra paperwork and no environmental improvements. From that point of view, it is better that both boundaries and Module A-D are included from the start.

There is a difference between steel and steel, but why is it not always the steel option with the lowest impact on the environment that is chosen? On the one hand, it can be due to the economy. It is way cheaper to by steel from other countries. On the other hand, it may depend on availability. If it depends on the economy, incentives may be required for clients to select the steel with the lowest impact on the environment. Another alternative is a lack of knowledge about the different steel options.

5.4 Steel

Strong, light, flexible and recyclable. The steel industry's description of the advantages of steel is in good agreement with the building industry's view, but few have thought about reuse of the material. Some of the structural engineers that were interview do not think this is a good idea, pointing out that there is no system for reuse in Sweden, a lot of work will be required, and it will be challenging to ensure the quality. Who should

be responsible if the construction collapses, and what about the availability? It will not be possible with today's strict requirements.

On the other hand, others that were interviewed see this as a permanent solution to the climate issue. Even if it requires extra work, it will be worth it. Examples show that it is possible and there are solutions to the problems mentioned above.

If the environmental gain is marginal in comparison with recycling, it might not be worth the extra work. But what if the production of new materials can be eliminated in the future due to reuse, then it will result in a significant profit.

When it comes to whether steel is more suitable for reuse than timber, at least two positions can be taken. On the one hand, it can be stated that both materials have been reusable before; however, to a small extent. On the other hand, since timber is an organic material and is sensitive to climate changes,
reusing wood can be a challenge. Creep and cracking also need to be taken into consideration.

Steel has a bad reputation concerning environmental impact that might be several reasons for that. On the one hand, it can depend on that module D often is excluded, and the potential of recycling and reuse are neglected. So, the entire life cycle is not taken into consideration, which means that production becomes of the highest importance. One the other hand, that might not be an awareness about the difference between steel produced in Sweden compared to other countries, steel scrap compared to iron ore, or the fact that high strength steel grades can contribute to solutions with lower impact on the environment compared to standard steel grades.

6 Conclusion

Because of the limited number of interviewed persons, only an indication of today's situation has been given. But based on the interviews and literature studies the following conclusions can be drawn

- There is no consistent application of LCA in the construction industry today. To prove this hypothesis, the same quantity as the other assumptions is not needed. If LCA is used in a consistent way, where all modules have to be included, you will get a fair assessment showing which option that is best from an environmental perspective. By excluding module D, which is often done today, you miss the reuse and recycling part. Considering long time perspectives, this can be of greater importance than the production.
- Today, economic interests are a priority over the environment. Since 20/21 persons agree with this statement, it indicates that that is the case today. Economy makes the companies go around, and money is often the limiting factor in the building industry today. Environmental awareness has increased over the last few years, and many suggest that companies will be forced to invest in the environment to survive in the industry. The study shows that there are significant differences between companies when it comes to investing in the environment. More prominent companies with higher budgets often have greater opportunities to invest in the environment. Incentives and requirements are needed even to have a chance to reach climate neutrality 2045. The economy is governing in the building industry, and there is no doubt about that. The question is whether the economy and environment will be equated in the future or not.
- Steel is a sustainable material, and in some cases, the most sustainable choice. This is partly based on the fact that steel is a circular material with a long service life, since its properties usually are unchanged unless it is exposed to fire, corrosion or fatigue. Compared to concrete and timber, steel is the only material that can be upcycled. It is perhaps not possible to say that a material is the most sustainable always and everywhere. It has to do with the application. It is vital with "the right material in the right place," and a hybrid will probably be the best solution, even in the future. It is hard to compete against steel if there are requirements for large open surfaces, slim constructions, high loads, or if explosion needs to be taken into account.
- The environmental benefits of reused steel make up for increased handling. None of the interviewed persons had worked with projects where steel have been reused, and neither of them was aware of the specific environmental benefits or the extra work. So, more research is needed to draw a conclusion. But it can be stated that steel is suitable for reuse, and in that way contribute to a circular building industry.

As shown in both literature and the interviews conducted, sustainability is a broad concept, and which material is the most sustainable depends on the situation. Since there is no standard method in the construction industry, where all aspects are included, it is difficult to prove which material is the most sustainable. But since steel meets many criteria mentioned in connection with sustainability, both in literature and during interviews, it can be stated that steel is a sustainable material.

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8 Appendices

List of interviewed people

Environment and sustainability experts

- Sara Nilsson, WSP, Environmental and Sustainability Consultant
- Susanna Toller, Trafikverket, Expert within the field of life cycle assessment
- Anna Denell, Vasakronan, Sustainability manager
- Mia Edofsson, Akademiska hus, Sustainability manager
- Per Löfgren, Tyrens, Sustainability manager
- Matilde Unge, Liljewall arkitekter, Sustainability Strategist
- Kristina Bengtsson, Brixly, QEHS manager

Architects

- Frida Wallner, Wingårdhs arkitekter, Architect SAR/MSA
- Per-Henrik Johansson, Liljewall arkitekter, VD and architect
- Rolf Eppens, Eppens Arkitektur AB, VD and architect
- Julia Jorns, Liljewall arkitekter, Architect and Environmental coordinator

Structural engineers

- Elias Fritzson, Cowi, Structural Specialist buildings, cowi west
- Rune Bu, Cowi, Structural engineer
- Jan Adolfsson, Peab, Structural engineer/manager
- Mårten Sandell, WSP, Structural engineer
- Johan Wikblad, KE-gruppen, Project manager and Structural engineers
- Andreas Elofsson, Ranaverken, Structural engineer/manager
- Hjalmar Nilsson, CM Byggkonsult, Structural engineer/ BIM-manager

Others

- Tomas Alsmarker, T Alsmarker AB, Wood Innovation Manager
- Kjetil Myhre, Norsk stålforbund, Manager
- Kristina Einarsson, Boverket, Project manager