Tampere University

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SUSTAINABILITY ASSESSMENT AND RE-USABILITY OF STEEL FRAMES

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TIIVISTELMÄ

Sayed Khalil Khalil: Teräsrakenteiden elinkaari
Kandidaatin opinnätetyö
Tampereen yliopisto
Rakennetun ympäristön tiedekunta
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Tässä kandidaatin työssä tutkitaan teräsrakenteiden elinkaari yleisesti ja keskitytään erityisesti käsittelemään teräsrakenteiden uudelleenkäyttöä. Työ koostuu teoriaosasta ja teräsrakenteita tutkivan rakenteen käsittelystä. Teoriaosuudessa on hyödynnetty tiivistetyn ja tutkitun akateemisten julkaisujen tietoja. Siinä käsitellään teräsrakenteiden uudelleenkäytön suunnittelumenetelmiä ja teräsrakenteiden uudelleenkäytön sovelluksia. Työssä verrataan toistuvasti teoriaosuuden tietoja työssä käsiteltyihin pienen teräsrakenteen tuloksiin niin kuin projektina. Arvioimme myös projektin elinkaari eri vaiheissa standardin EN 15978 laskentamenetelmän mukaan.

Teoriaosuudessa tutkitaan teräskomponenttien uudelleenkäytön perusteita, niihin liittyviä standardeja, koodeja, etuja, haasteita, suunnitteluperiaatteita ja ennen kaikkea, teräskomponenttien uudelleen käytön soveltuvuutta rakennusprojekteihin. Lisäksi alun perin mainitun pieni projekti ei ole suunniteltu uudelleenkäytön varten. Kuitenkin, siinä sovelletaan ja verrataan DfD:n periaatteita havainnollistamaan enemmän teräsrakenteiden uudelleenkäytön teoria.

Tässä asiakirjassa ehdotetut tekniset ratkaisut perustuvat pienen projektin tutkimukseen, jota voidaan soveltaa täydellisesti pienikokoisiin rakenteisiin. Keski- ja suurikokoisissa rakenteissa ovat mahdolliset tekniset ja taloudelliset esteet. Pienen menestyneen projektin tuloksia voidaan käyttää esimerkkinä suurempien projektien teknisten asioiden ratkaisemiseen. Lisäksi pienen projektin suunnittelu on yksinkertaista, sen muoto on säännöllinen, suurin osan sen pääkomponenteista ovat identtisiä ja ylläpitävät merkittäviä kuormia yksinkertaisilla liitoksilla. Kaikki edellä mainitut ominaisuudet ovat tärkeitä teräsrakenteen uudelleenkäytön kannalta.

Kaiken lisäksi hankkeen elinkaariarvioinnilla (LCA) on laskettava sen suhteelliset ympäristövaikutukset. Tutkimuksen laskelma on suoritettu parhaiten realistisissa skenaarioissa indikaattoreina terästuottajien tuoteselosteista (EPD) saadut yksikkötiedot. Laskelman tulos antaa projektille ekvivalentin CO_2-tuotannon sen elinkaaren eri vaiheissa. Voimme myös laskea, kuinka teräksen kierrätettävyys ja uudelleenkäytettävyys vähentävät sen ympäristövaikutuksia.

Avainsanat: Teräs, Uudelleenkäyttö, Kierrätys, Elinkaariarviointi, Kestävyys, purettavuuden suunnittelu, Kierrätystalous

ABSTRACT

Sayed Khalil Khalil: Sustainability assessment and re-usability of steel frames
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This thesis aims to analyze the lifecycle of steel structures in general with a specific focus on their re-use. This work is divided into two main sections, the first dealing with the theoretical background and the second part describing a small steel structure. The theory section summarizes the relevant academic research papers, design methods, and applications of the re-use steel structures. The second section presents an example of a small steel structure that compares it with the theoretical principles. We will also assess the life cycle of the project at various stages according to the EN 15978 calculation method.

The theory section explains why steel components are re-used. It examines the relevant standards and codes, and the benefits of and barriers to re-use. It also describes the design principles and, most importantly, it states whether this concept is applicable to other construction projects. The example steel structure is not specifically designed for re-use as this would require a deep knowledge of structural design. However, it applies the theoretical design principles to the project to illustrate more about the re-use of steel structures.

The technical solutions proposed in this paper are based on the study of the small example structure, but they should be applicable to other small structures. Although there may be technical and economic barriers to applying these solutions to medium and large steel structures, a successful small project can be used as a model to solve technical issues in bigger projects. The design of the small structure used in this project is simple. It has a regular shape, most of its main components are identical, and it can support significant loads with simple joints. All of these features are the basic principles for the design of re-usable steel structures. Finally, the LCA calculations used for the project provide us with information about a structure's environmental impacts during the various life cycle stages in its lifecycle.

Above all, the life cycle assessment (LCA) of the project takes into account the related environmental impacts. The calculation is based on realistic scenarios using unit data obtained from the steel producers' product declarations (EPD) as indicators. The result of these calculations indicates the structure's equivalent production of CO_2 at various stages in its life cycle. The calculations also show how the recyclability and the re-usability of steel reduce its environmental impacts.

Keywords: Steel, Re-use, Recycle, Lifecycle assessment, Sustainability, Design-for-Deconstruction, Circular economy

The originality of this thesis has been checked using the Turnitin Originality Check service.

ALKUSANAT

Tämän kanditatin opinnäytetyö on suoritettu Tampereen yliopiston rakennustekniikan osastolla ja se on kirjoitettu apulaisprofessori Kristo Melan johdolla. Arvostan kovasti hänen avustustaan tässä asiassa.

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SYMBOLS AND ABBREVIATIONS

GWP_i	Global warming potential of module i of the building
LCA	Lifecycle Assessment
LCI	Lifecycle Inventory Analysis
LCIA	Lifecycle Impact Assessment
DfD	Design for Deconstruction
EPD	Environmental Product Declaration
BIM	Building Information Management
SEEA	System of Economic and Environmental Accounting
BREEAM	Building Research Establishment Environmental Assessment Method
LEED	Leadership in Energy and Environmental Design
BS	Blast Furnace
EAF	Electrical Arc Furnace
BOF	Blast Oxygen Furnace
ULCOS	Ultra-Low Carbon Dioxide Steelmaking

1. INTRODUCTION

The potential dangers of climate change are becoming more obvious to the global community nowadays. Governments are trying to limit and undo its impact as soon as possible, and they must cover all possible fields to meet the expectation including the construction industry. The EU is trying to reduce its total energy consumption of fossil fuels 30% by year 2030, and the construction sector may contribute extensively in this regard. [1]

All this would be possible if we could address the issue of sustainability in the construction industry, especially in buildings. According to European legislation, a sustainable building must have minimal impact on the environment in terms of water, material, and energy resources throughout its lifecycle. The lifecycle of a building includes the stages from extraction, demolition, and recycling or re-use of material. In addition, the lifecycle concept seeks to lower material waste production and re-use bulk of the produced waste. According to the European waste framework directive, the building industry needs to achieve 70% of the potential for re-use and recycling. [1] & [2]

On the way to address sustainability is to assess the potential environmental impact of a building. Lifecycle assessment (LCA) provides us the tool to do so. The assessment can be done according to the calculation method prescribed in EN 15978. The method of calculation considers the realistic conditions of a building, and the result indicates its environmental impacts in numbers. The result may also imply how the recyclability and re-usability of a material positively affect sustainability.

The re-use of steel structures may provide more potential for the recycling industry. Recycling and re-using components of the building or other infrastructure that were designed to be disassembled and reused is essential to sustainability [3, p. 3]. For instance, scrap steel is the main raw material for steel structures such as profiles, merchant bars, and heavy plates in Europe. This means, providing steel from scrap reduces primary energy used in an electrical arc furnace (EAF). Besides, blast furnace (BF) steel, which is produced from iron ore, leads to a construction material that can be recycled infinitely from every ton of primary steel. Both of these practices play an important role in reducing the carbon footprint of the steel recycling industry. That is why the use of steel structures has grown so rapidly in Europe over the last few decades. [4, p. 72]

Recycling is a sustainable approach toward minimizing the production of waste material in the environment. However, a newer concept of design-for-deconstruction is a more effective way of recycling materials, especially for steel structures used in the construction industry. This approach will effectively reduce the production of waste and the consumption of energy in the recycling process almost to zero. The main idea is to improve the design and construction of steel structures so that the main components can be dismantled and re-used repeatedly. [5, p. 23]

Recycling and reusing steel structures have their own challenges and benefits. The most important challenges are how to reduce the time, cost and labour needed to deconstruct a building. This poses many technical challenges. Also, the cost of steel re-using, and re-certification, design, and application of the steel structures are other barriers. [6]

In contrast, the main benefit considering steel reuse would be environmental such as energy, carbon, and other impacts that are saved. Besides, increased demand would create more businesses especially deconstruction specialists and contractors, stockholders, and suppliers of re-used steel, which would also help to create additional employment. [6]

Generally, this thesis aims to outline basic knowledge of the lifecycle of steel structures and to assess the potential for recycling and re-using their components. The thesis will also provide a lifecycle (LCA) calculation of how a steel structure project impacts global warming in terms of CO_2 emissions.

This thesis reviews the literature about the sustainability of steel frame structures. It also illustrates how the recyclability and re-usability of steel material help with sustainable development. In addition, it introduces basic principles of steel structures and applies them to an example-steel structure project accordingly.

The demo-project is a small steel frame structure that acts as a model for more complex projects. The purpose of the demo-project is to research and answer two main questions. Firstly, is the basic principle of steel frame re-usability applicable to real projects, and if so, how can it best be applied. Secondly, how to assess the lifecycle of a steel structure to get a single number that can be used to assess its impact on the environment.

2. SUSTAINABILITY IN CONSTRUCTION

Earth experienced climate changes many times in the past two millennia, however, it has sped up since the industrial revolution. Previous changes were patchy happening in various parts at different times. In contrast, human-caused climate change has affected the entire world simultaneously. Human-caused greenhouse gases are the primary reason for mis-balancing the Earth’s natural greenhouse, and carbon dioxide are on top of the list. The temperature on earth is a balance of the sun’s input energy and its conversion back to the atmosphere. Data shows CO_2 concentration has increased about 30% from the pre-industrial era till now [7, pp. 1-11]. This has caused and will continue its series of effects on the earth and humans such as weather, land, ocean, and economy, society, and lifestyle, respectively.

The prominent reason behind global warming is the extensive use of fossil fuels, which are emitting carbon dioxide into our atmosphere, and it has a direct connection to humans’ activities especially since the industrial revolution. However, humans are also capable of preventing and reversing the course of the global warming by perusing a sustainable development by collaboration. A good example of cooperation among global community is the Paris agreements. The aim is to treat climate change by keeping a global temperature rise below two degrees Celsius in this century [9]. It can also achieve sustainable development by bringing changes in economic, energy production and consumption, protection of natural capital, and food and water destitution. [4, pp. 11-12]

According to the European commission of environment, a Sustainable building has the following characteristics. A sustainable building uses less energy and materials, and it is healthier with comfortable spaces. It has a lower environmental impact throughout the whole lifecycle, and it has a low cost to run, and it is still a more valuable property in the long term. Most importantly the building material and components are recyclable and possibly re-usable at the lifecycle-end. [8, p. 17]

The EU construction sector has had a significant impact on environment, and it is also in forefront of combating to minimize and reverse the condition. The construction sector has a 40% energy consumption rate, 50% extracted material consumption, and responsible for about 36% of GHG emissions of the total EU CO_2 emissions. In addition to providing a safe environment for the construction workers and occupants, the EU has leaned to apply circular economy principles on the design and construction of buildings and has provided legislation and standards to guide this sector toward sustainability. [9]

The three key aspects of sustainability of a construction project are environmental, societal, and economic sustainability. It is also worth mentioning to consider existing buildings in initial city planning as keeping existing buildings avoids material waste, saves land and heritage, and should be rehabilitated as if new buildings are created. Specifically, in the building sector, the design stage has a huge impact on a building lifecycle and sustainability. Positive impacts can be achieved by the establishment of basics goals, comprehensive integral planning considering the whole lifecycle of the building, and good quality management. The major purpose of sustainable construction is creating high-quality buildings by considering environmental, societal, and economical sustainability. Below figure 1 illustrates various measures of sustainable development between three main overlapping fields. Every field represents an aspect of sustainability, and the overlapping area of two fields measures fair use (Social, Ecological), righteous growth (Economic, Social), and continuous profitability (Ecological, Economic). The overlapping area of all three fields measures sustainability (Ecological, Economic, Social) at the center of the figure. [4, p. 2]

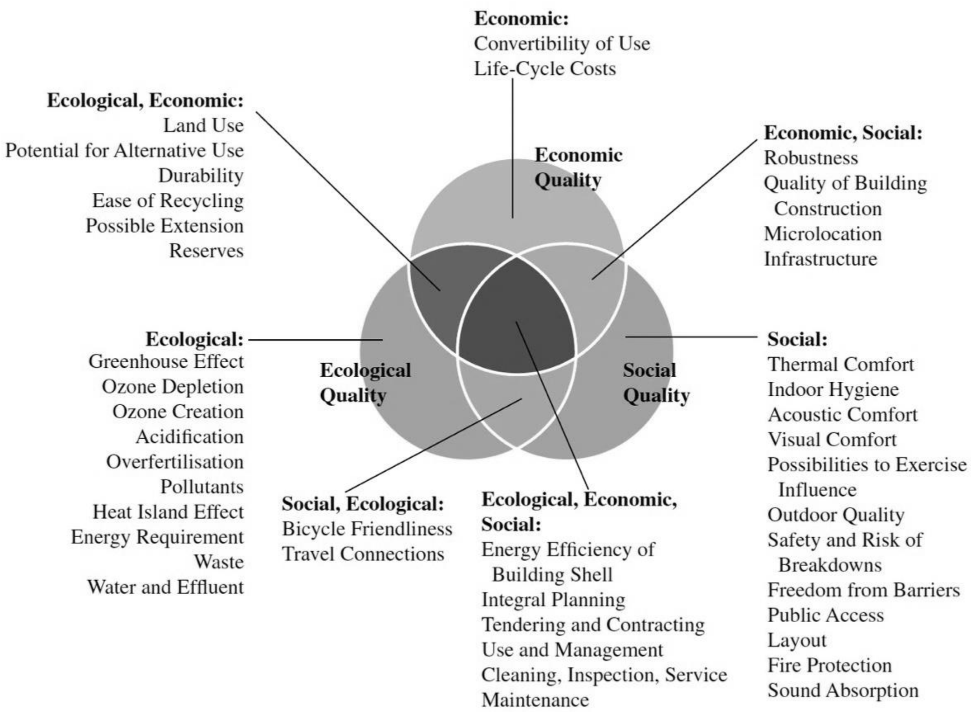

Figure 1: sustainable buildings concerning their ecological, social, and economic quality. [4, p. 7]

2.1 CIRCULAR ECONOMY AND SUSTAINABILITY

As the tendency grows toward a sustainable approach for the environment, there is also an approach to consider the circular economy as another sustainability initiative. The term circular economy (CE) is used against the linear economy and the very basic aim to maximize the value of material and encourage for creation of a recycling-oriented society. Although the circular economy (CE) has been poorly applied mostly in the built environment, there has been rising awareness to relate and apply on the construction process, especially design and selection of material. To maximize the benefit, we must consider circular economy aspects into construction lifecycle stages. [10]

The design is a crucial stage for products including in construction, and there are options to think about to improve product circularity. All designers of various fields may work together as a team to apply the eco-design process ensuring product circularity. Designers such as architects, engineers, product designers, chemists, packaging design, etc. Designers may focus on products from as early as material sourcing, manufacture, distribution, maintenance, to design for end-of-life. This consideration will add to the value of material as it will be used repeatedly [9, pp. 23-26]. For instance, steel material can be a good choice for end-of-life designing products. It has the characteristics to be recycled and re-used repeatedly. However, steel also has its own challenges accordingly.

There are challenges to implement the CE in the construction sector. Firstly, how to address the necessity of the client in long-term. We can improve the quality of the building by extending its life span, and simply its design for the client's comfort and use. Secondly, how to encourage investors to invest in providing secondary materials with proper quality and certification and investors find suitable market subsequently. And thirdly, there are barriers that needed to be solved on the material, product, and construction process in the CE.

The material barriers can be solved by ensuring enough quantity of it for a viable economic supply chain. Products have enough infrastructure and money for recovery, transport, and reprocessing. Construction of a structure includes product installation, de-installation, store, and transportation at the site. there is also a lack of standardization and data-sharing within the construction sector. However, steps are taken to overcome mentioned issues. [9, pp. 75-79]. for instance, Design for Deconstruction (DfD) is a standard design tool to modernize building design. In addition, building information models (BIM) is another tool for providing information about circularity for designers, contractors, and manufacturers.

In calculation, the circular economy (CE) is a far more favorable option than the linear one for a sustainable environment. However, there is a lot of work to be done in all various fields to make it viable technically and economically, and a broader collaboration is needed between economists and scientists. As for the construction industry, it is important to have new technologies and tools to produce and design structural components that can be effectively recycled or reused. [5, p. 18]

2.2 THE LIFECYCLE CONCEPT IN CONSTRUCTION

Nowadays the life-cycle concept is related to the creation of high-standard buildings, where not only their whole life is assessed and designed, but also after they are deconstructed, recycled and re-used. This needs a comprehensive panning from raw materials needed for the construction products to the building material after being disposed of or recycled. The comprehensive plan must cover all building's life stages such as design, production, construction process, use, possible conversion, and deconstruction stages [4, pp. 29-32]. To create a comprehensive plan, and manage the project's time, recourses, and information accessibility, we need tools. Fortunately, there are some available such as Life Cycle Assessment (LCA), Building Information Management (BIM), Environmental Impact Assessment (EIA), System of Economic and Environmental Accounting (SEEA), and BREEAM and LEED which provides green-building rating in construction. We will discuss some of the tools most common in the construction industry relatively in detail later.

2.2.1 LIFECYCLE ASSESSMENT

LCA is a complex scientific tool, and basically, it analyses potential environmental impacts of a construction product and a project itself throughout its lifecycle. The analyses may cover the environment, human health, and resources, and can be done in phases of LCI (lifecycle inventory analysis), LCIA (lifecycle impact assessment), and interpretation. For instance, the potential emission output of a construction product may be determined by its inputted data at the LCI phase. Subsequently, it is calculable to see the potential environmental effect of the product by outputted data at the LCIA phase, and the outcome may influence our decision-making regard to design, material types, and application method on the construction site [11, p. 2].

However, there are limitations in LCA in the calculation. It is difficult to consider all relevant environmental impacts stated by the frameworks during LCAs studies. There are also uncertainties in using LCA data. For example, LCI phase inputted data are generated from the average of all possible impacts in the construction industry. The generated inputted data may ignore some other impacts that happens during a project such as impacts of material transportation to the site. Choosing an LCA methodology for the data analysis and assessment may cause some uncertainties too. Another limitation can be a determination of ideological and ethical values in an LCA calculation, which is hard to do so. [12, pp. 229-233]

In this thesis, we are going to calculate the LCA of a small steel structure at various of its lifecycle stages according to EN 15978. The LCA calculation will be focused solely on environmental impacts.

LCA can assess the environmental impact of steel structures at different stages of its lifecycle. There are four main stages plus a supplementary part as shown in figure 2. The product stage (Module A1-A3) is a preparation of steel raw materials, transportation, and steel frame production. Construction stage (Module A4-A5) covers transportation and installation of steel frames from the factory to a construction site. The use stage (Module B1-B7) covers possible scenarios during building occupancies such as maintenance, repairing, replacement, refurbishment, use of energy and water. The end-of-life stage(C1-C4) is the process of dismantling the building, material transportation, and management of its waste. The supplementary part (Module D) covers the positive impact of steel material aspect regards to environment. [13]

Product stage			Con-struction stage		Use stage							End of Life stage				Benefits and loads beyond the system boundary
Raw material supply	Transport	Manufacturing	Transport to the site	Assembly	Use	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	Deconstruction demolition	Transport	Waste processing	Disposal	Reuse-, Recovery-, Recycling-potential
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D

Figure 2: *Modular information for the various stages of a building assessment [4, P30]*

In LCA there are various types of indicators through the building lifecycle stages. Many types of indicators are described in EN 15978. However, we are only interested in the Global Warming Potential (GWP) indicator, as we are only calculating the potential amount of CO_2 of a structure in this study. Indicator unit data are obtainable from steel manufacturers' Environmental Product Declaration (EPD) document, and other LCA report databases. To consider all indicator for a project, the value of all indicators is calculated for each module of the lifecycle stage as figure 3. [13, p. 45]

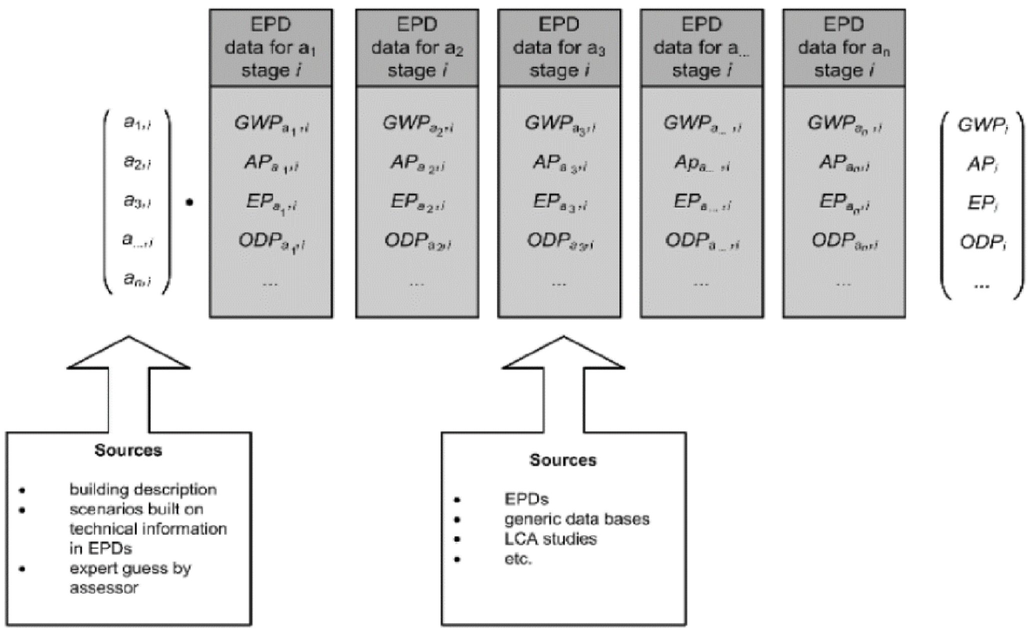

Figure 3: *Calculation matrix of environmental impacts according to EN 15978 P [13, p. 45]*

For modul $i = [A1, A2, A3, A4, A5, B1, B2, B3, B4, B5, B6, B7, C1, C2, C3, C4]\ and\ [D]$

As we need to calculate only GWP for this study, this complex matrix-equation will be simplified accordingly.

$$GWP_i = a_{1,i} x GWP_{a1,i} + a_{2,i} x GWP_{a2,i} + \cdots \ldots + a_{n,i} x GWP_{an,i} \quad (1)$$

Where; GWP_i is the global warming potential of module i of the building, $a_{n,i}$ is the quantity material of the specific building part. And $GWP_{a1,i}$ is the LCA data unite of the specific material of $a_{n,i}$ obtained from product manufacturer.

2.2.2 BUILDING INFORMATION MANAGEMENT

BMI is a handy tool to create and evaluate a construction project's lifecycle long before it exists, and especially it is suitable for steel structures. This program provides engineers the ability to create virtual 3d buildings with details, store and receive needed data from various project departments, and most importantly to supervise project information such as logistics, schedule, and cost. Besides, a designer may consider and try many options of building components best suited in terms of structure types, connections, and measurements. It also allows to compile various project information on the database and, providing a handful of information starting from the first done project. These will all influence better designing and avoid waste production, and it will available the platform to design for re-using of building components. In summary, engineers may evaluate their designs and realize the project's sustainability and applicability. [4, pp. 32-37]

Generally, BIM is focused on project visualization and estimation, and currently, there is a limitation on helping designers for specifically design-for-deconstruction approach. However, it is improving constantly and rapidly. Re-using of material on BIM is basically through LOI (level of information), which creates an accurate material specification of components with affixes to easily reachable such as manufacturing data, material grade, properties, and other technicalities. There is also the possibility of merging BIM and LCA to get a better result, and some have already developed these ideas. However, it is still in the preliminary stage of exchange data. Still, it is easier to update design and project data in one merging software rather than in two by designers. Enriching BIM data must be a primary target, and with the collaboration of other assessment approaches, designers and other project players may have a handy tool to improve on re-suable construction projects. [14]

2.3 NORMS AND STANDARDS

To standardize construction activities, it is important to have basics and there are important references accordingly which promote sustainable construction. The most important ones are (ISO) the global association of standards organizations, The European standards (EN) which are prepared by the European committees for standardization (CEN) and national institutes such as the land use and building act and the National Building Code of Finland. [15] & [4, p. 12]

In addition, the European Commission has already considered and adopted other legislations, guidelines, and frameworks to promote sustainable construction such as The Circular Economy Action Plan and specifically the Level(s) framework in 2020.

Level(s) is a provided tool with its framework under The European Green Deal to assist architects, builders, and related authorities to improve the sustainability of buildings throughout their lifecycle. The main aim is to achieve EU and Member State environmental policy by focusing on fundamental concepts at the building level using existing standards and level(s) framework [8]. We have also had other frameworks such as standard EN 15804.

EN 15804 is a European standard code providing rules for conducting lifecycle evaluation of building products and is complemented by another code EN 16485 specifically for wooden construction buildings. According to EN 15804, building products must be divided into stages for their lifecycle assessments and results by reporting production stages on modules A, B, C, and D as shown in figure 2. Product stages are considered during production, construction, use, demolition, and recycling [16]. This standard code has revised and updated on 21 June 2019 substantially by the European Committee for standardization (CEN) [17]. Other important technical standards are EN 15978 and EN 10025.

EN 15978 standard guides how to calculate and assess the environmental impact of new and current buildings [18]. And EN 10025 standard generally covers the technical delivery conditions for hot rolled steel structure products and consists of sub-parts accordingly [19].

2.3.1 EU WASTE LEGISLATION

Waste Framework Directive of 19 November 2008 is agreed legislation of EU countries for waste management basic rules. In Finland, waste legislation covers almost all waste for radioactive ones, and additional environmental protections are also considered accordingly. The most prominent legislations are Waste Act 2011 and Waste Decree 2012. Specifically regard to metal, End-of-waste Council Regulation decides of scrap steel to become waste [18]. In addition to all, article 4 of the EU Waste Framework has prioritized wase based on prevention, re-use, recycling, recovery, and disposal. [4, p. 20]

The main goal for all these legislations is to provide efficient product manufacturing suitable for recycling and reusing, and according to EU Waste Framework legislation, a rate of 70% recycling and reusing was sat by this 2020 for the construction industry. According to figure 4 below, steel, and metallic construction has already exceeded the target.

Average End-of-Life Scenario

Product EPD	Recycling (per cent)	Reuse (per cent)	Collection Loss/ Disposal (per cent)
Bauforumstahl: Structural steel: open-rolled sections and heavy plate	88	11	1
Hot-dip galvanised structural steel: open-rolled sections and heavy plate [5]			
Akkon Steel Structure Systems Co.: light gauge steel profiles	70	0	30
IFBS: profiled steel sheeting for roofs, walls and ceiling constructions	90	0	10
Tata Steel: Colorcoat assessed cladding systems (trapezoidal profiled sheet for roofs and walls)	79	15	6
ThyssenKrupp Steel Europe AG: PLADUR, sheet, strip and single-skin construction products	90	0	10

Figure 4. "Average end-of-life scenarios for steel products." [4, p. 21]

In Finland ‘Waste Framework Directive’ is based on national standards and the most important is the waste act, waste tax act, government decree on waste incineration and landfills, national waste plan, land use and building act, municipal waste management regulation, and general condition for building contracts. [5, p. 24]

3. REUSE OF STEEL STRUCTURES

3.1 STEEL FOR CONSTRUCTION

Generally, steel industry products can be organized into three main lines of crude steel, semi-finished steel, and finished steel, and in construction, mostly semi-finished and finished steel is used. The main elements are steel plates, standard sections, and compound sections. The standard sections frequently used by a designer can be mentioned as hot-rolled sections, standard welded products, and cold-formed ones. [20, pp. 19-25]

Steel can be an ideal solution for sustainability in construction, and it is verified by various assessment tools and methods. For instance, SBTool and LEED consider steel structure the best performers related to energy, health, and comfort attributes, and recycling respectively [19]. There are other prominent advantages of steel structure such as the possibility of design for re-using to reduce waste production [21], and most of the wastes that were produced are valued by scrap dealers.
Also, most steel structure preparation is offsite, and will take less time for the installation at the site, so this has a direct impact on overall project cost [22, p. 203].

3.2 THE STEEL RECYCLING AND REUSING CONCEPT

Steel construction has grown vastly in Europe in recent decades [4, p. 72]. This will add huge pressure on steel sourcing and its related technology accordingly. It has an impact on the environment too. For this reason, the concept of recycling and re-using aims to reduce using of raw material as the main source for steel products [4, p. 73]. Recycling is a process where a used material can be processed to another usable material without being discarded and wasted completely [23]. For example, steel scraps are gathered and molted by basic oxygen furnaces (BOF) or electric furnace systems (EAFs) systems and to make steel structure components such as beams and columns.

Reusing steel is a relatively new idea has structural steel is inherently reusable and it is different from practicing recycling by remelting. Reuse is technically possible and as demonstrated by limited projects. Generally reusing of steel structure as less impact on greenhouse gas emissions than its recycling, and it is possible to reuse a whole building or part of the buildings such as trusses, beams, or columns. [5, p. 23]

3.3 STEEL RECYCLING

Steel can be recycled infinitely without degrading its material properties by melting [24, p. 23], and it is recycled by steel converter Electric Arc Furnace (EAF) from scarp by melting. The converter charges the furnace in a mixture of hot metal scrap and the heat is supplied from the oxidation of carbon and silicon in the hot metal. The production line has various routes such as EAF, Blast Furnace (BF), and BOF. These different routes have various energy consumption and waste production rates, and the sustainable approach is to minimize both.

In recycling, the net amount of saved material is very important. Steel scrap that is to be recycled minimizes raw material demands, reduces production energy consumption and CO2 emissions. For instance, for steel production, the BF route is the first step with iron ore as raw material, which requires high energy consumption. The BF route usually produces usually high CO2 emissions. However, using steel scrap from a dismantled bridge, for example, a heavy steel plate, for a second lifecycle by being remelted in an EAF, requires about 50% less energy, and produces less emission considerably [4, p. 74]. Below figure 5 indicates steel material production and recycling at various stages.

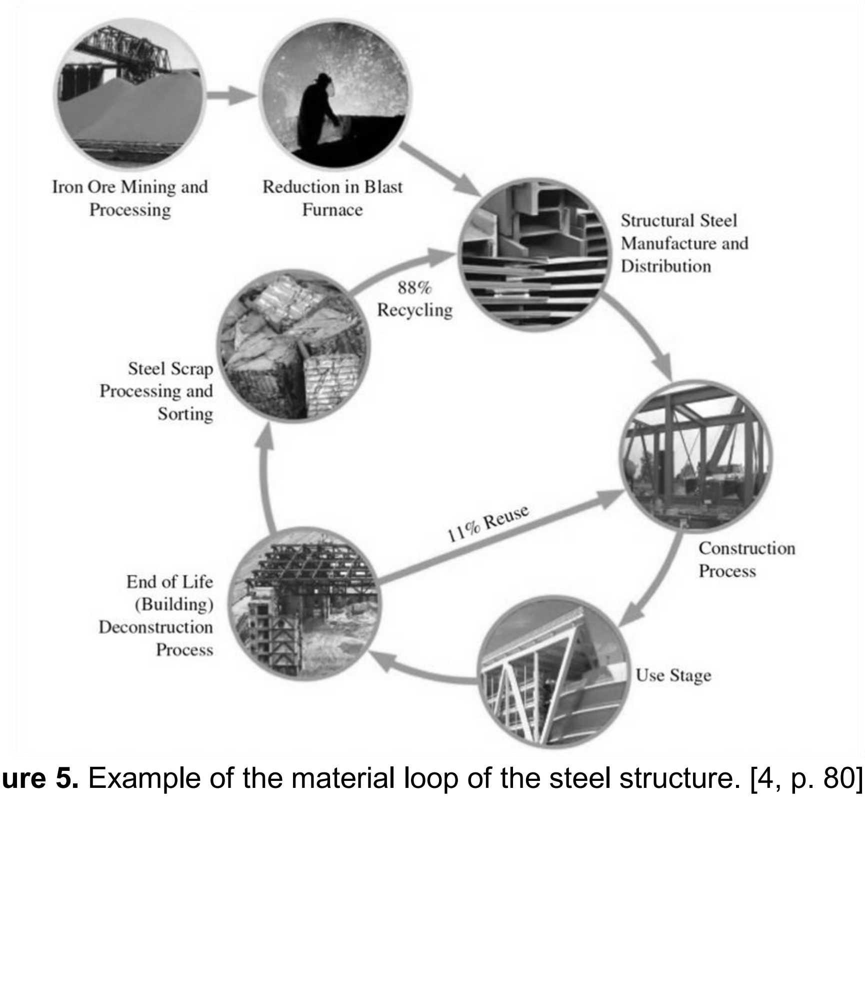

Figure 5. Example of the material loop of the steel structure. [4, p. 80]

As a simple example according to the LCA lifecycle assessment, the required energy consumption to produce a steel product from iron ore in the BF process is about 26MJ/kg. It was assumed that 14MJ/kg energy is to extract pig iron from ore and 12MJ/kg for following the steelmaking process. However, to produce the same steel product from material scrap by EAF process is about 12 MJ/kg, over 50% less. [4, p. 75]

As mentioned above, one of the approaches to make steel recycling more sustainable is to use the EAF in state of the BF, and the BOF as much as possible. This leads to the reduction the CO2 emissions [25], energy consumption [4], and waste production. However, steel industries may not rely just on steel scrap as it would not fill the demand, so they must continue production from the raw material of iron ore. It is possible to use hydrogen from iron ore reduction, as the technology allows to produce steel from reduced iron DRI (solid sponge iron) or HBI (hot briquette iron), pig iron, and scrap steel together [19].

CO2 makes up about 93% of all steel industry's greenhouse gas emissions [22], and of most the gas emissions produces during steel production in the furnaces resulting from chemical interaction between coal, coke, and iron ore. it is again possible to benefit from new approaches such as the ultra-low carbon dioxide steelmaking (ULCOS) to effectively reduce it [25]. The aim is to redesign the furnace so it can store the CO2, and later recycle or reshape it to a less damageable element for the environment. Energy efficiency, improving recycle rate, automation steelmaking production, and modernization may have a significant impact accordingly [26].

3.4 RE-USING OF STEEL STRUCTURE

As discussed in section 2.4, recycling steel structure would have a significant impact on energy consumption and waste production than steelmaking from raw materials. However, if steel members are saved without notable damage from structure demolition, they can be re-used. Re-using steel members will reduce environmental impact 96% [6] than steelmaking from scrap. This is a concept still in rare practice in the construction industry.

The motivation for engineers toward re-use is primary environmental impact, as an example, the CO2 emissions reduce about 45% [27] by re-suing compare to producing new ones. However, there are other positive aspects too. For instance, it may cause a 15% reduction in the project total cost for re-using steel members that require refabrication, and a 40% cost reduction if steel members do not require it [28].

According to the European waste directive, re-use means of using products and elements again for the same purpose without being discarded as waste [29]. Re-use of construction material is relatively high in Europe, especially in Finland about 26% [28, p. 6].

Generally, in steel structure, a re-usable member circulates via a cyclic process of design, fabrication, construction, maintenance, dismantling, and storage. It is a complex process and needs a coordination environment among all who are somehow involved in the project. The BIM is well-designed tool to manage the smooth transfer of the member and re-designing it.

Designers' role is prominent, and their documentation not only should cover all project lifespan, but also, demolition and structure dismantling period. Re-fabricators take care of structure dismantling, storage, and assembling to a new building based on design. Currently, demolition technics with heavy machinery led to a lot of waste production, However, by careful disassembling methods, re-used steel members can be obtained without serious damage. Material dealers often take care of the market. They arrange, grade, and batch the member, and try to find new users for dismantled members directly from a demolition site or from storages. [28, p. 13]

There are various types of re-use, each one with its own characteristic, such as in-situ (same as the current location of the steel structure) re-use and ex-situ (outside of the current location of the steel structure) reuse as table 1 below.

Table 1: *Steel structure re-use variants [29]*

	In-Situ Re-use	Ex-situ Re-use
Steel Structure Reuse	Reuse of the main components of the steel structures on site.	Dismantling, transferring and reassembly of the steel structures out of site.
Components' Reuse	Reuse of some parts or some components of the steel structures on site.	Reuse of some parts or some components of the steel structures out of site.
Elements' Reuse	Dismantling, and reassembly of elements for the steel structures on site.	Dismantling, and reassembly of elements for the steel structures on site.

3.5 BARRIERS OF RE-USING OF STEEL STRUCTURE

Although steel structure recycling and re-using has great potential in sustainability, it is not easy to apply considering there are significant barriers. The complexity of barriers somewhat varies and depends on factors such as economic, social, technological, and legal issues [26]. The most important barriers that can be outlined are the technical barrier, lack of demand and coordination, lack of information, material storing, [29], sourcing of steel, cost implication, and certification [6].

Technical barriers can be faced almost in all processes of steel structure recycling and re-using. Technical barriers are not static and can be changed over time. In the demolition and dismantling stage, welded shear studs that connect metal decks to beams may prove very difficult to recover floor beams without notable damage [6]. Or testing ability, whether recovered steel member is re-usable. The earlier problem could solve by proper cutting of joint technics, or a new initiative to apply standard bolted [29] joints in future designs, but these could affect the overall project schedule and labor cost. However, by the advance of technology and improvement of science in this field, a balanced solution could be found to tackle this issue.

Lack of demand and supply chain comes primarily from lack of motivation to improve and apply the concept of re-using on the steel construction industry. Proper leadership especially from governments and engineers could encourage change by illustrating that the concept can be more cost-effective, the material has quality, and the market has potential growth. And to tackle the lack of information for building construction history, design, used members and elements, a central database is needed, and hopefully the BIM is a remarkable tool in this regard. The BIM may also store data about the availability and storage of dismantled steel members, which may link refractors, contractors, suppliers, and designers with each other. [29]

Another issue with not having proper supply chain and central data information is re-used steel structure sourcing. A structural designer may not find proper sections to fit parts of the building, this would directly affect project design, timetable, cost, and lay confusion and resistance among client, contractor, builder, and supplier.

The cost of re-used steel members could come from extra labor to carefully dismantle members from a demolished structure, and it adds to the extra cost of prolonging the project schedule. In addition, member’ prefabrication, testing, and quality certification has its impact, and all this add to an extra cost of 25% [6] for re-using of the steel structures.

The CE-marking is currently ensuring existing construction material quality, and to apply for re-used steel structure, it needs a new procedure for quality control, especially, it is hard to track data about the steel member manufacturer [30, p. 43], However tensile testing [6] to determine the yield strength by sampling could be a solution. If the members are from various projects and manufacturers, this itself becomes a barrier cost for the concept.

3.6 DESIGN-FOR-DECONSTRUCTION (DfD)

The design-for-deconstruction (DfD) concept is relatively contemporary idea for dismantling, recycling, remanufacturing, re-using, and eventually redesigning of the steel structure members [5]. The main goal is to design a steel project not only for its lifecycle stages but also for end-life purposes too. Generally, this principle can be applied to any construction material that can be recycled or any development that is modular and self-contained and has an integrated heating and cooling system. However, it has specific implications on steel projects where components are re-used again not recycled [31] . Design-for-Deconstruction (DfD) causes efficiency, adaptability and, disassembly in a building and decreases pollution, but building dismantling technology, cost and time schedule are the main barriers to this concept.

There are basic principles for this concept, and the most important one is the design stage. Steel building must be designed in a modular, prefabricated, and simple structural system, and joints must be simple like using bolts and no welds, easing the construction and deconstruction process. Moreover, joint fasteners must be considered removable like screws, not nails or other types of adhesive chemical materials. In addition to all, maintenance and renovation of the building must be easily accessible and renewable. And at last, the design process must minimize using of building components and materials as much as possible. [5] & [4]

The design-for-deconstruction hierarchy is established upon design, construction, elements, components, sub-components, and other materials. Components and sub-components are the main parts of the steel building which are on the focus of design for re-use and remanufacture. Subsequently, to ensure the quality of re-using of components, some tools can determine critical factors for disassembled components at the end-of-life stage in design-for-deconstruction (DfD) concept. Quantity and material characteristics of components depend on cleanliness, design and technology cycle, size, number of modules, and their functional complexity [31]. Design-for-Deconstruction is in fact design for demolition and deconstruction.

3.7 DEMOLITION AND DECONSTRUCTION

In steel construction, demolition and deconstruction mean to recover current building members, such as main components, sub-components, and others either for the re-use or recycle. The goal is to maximize re-use of most of structure components, and it is not practical to design to re-use all building's parts. For instance, doors and windows would not have the same quality to be re-used again later. The concept of demolition-and-deconstruction should be processed as hierarchical design such as on top design-for-reuse, then design-for-remanufacturing, and on bottom design-for-recycling. [31]

Demolition of a building needs proper planning with many phases such as project-, structural-, work phase-, and weekly planning [5]. All phases are to ensure time and cost-effectiveness of project process, labor safety, and material safe recovery, storage, and transfer for inspection and re-use into a new construction site. All the process is frequently inspected by the engineers and authorities from start to end.

Deconstruction of a building is to get material from a demolished building and integrated it into a new building. Steel structure components pass the process of inspection, storage, and transfer, before re-using them into a new structure, and of course, quantity and quality have fundamental effects on redesigning them. Cost and energy consumption define the success of the deconstruction process, the simpler design of a building, the more effective is for demolition and deconstruction. This process has its own goals. Rapid and careful demolition, prevention of waste, and prevention of damage to the steel components. The overall cost and environmental impacts must be reduced as much as possible for the process. Most importantly, the structure must be designed somehow, that ensures the longevity of the building, and it would not need a demolition and deconstruction process for a quite long time. [31]

4. RE-USABILITY AND LIFECYCLE ASSESSMENT OF A PROJECT

As mentioned, steel is a completely recyclable material. However, the current steel raw material and recycling rate are not enough for future demands. New concepts must be considered to reduce using of raw and recycled material in steel construction. One of the proposed concepts is the principle of design-for-deconstruction (DfD). The design-for-deconstruction (DfD) provides flexibility in a broader sense such as transform one building function to another such administrative building into residential or vice versa [4]. In a technical sense, especially for steel structure, this concept advice for simple components with a traceable database, easy connections, adaptable design, and detailed plan for dismantling or re-functioning the whole building [5].

In steel structures connections have an impact on the DfD success, the most unsuitable one is welded- and riveted joints as components are difficult to separate without damage. Standard bolts and screws are the most suitable ones, along with slip-resistant bold. It easy and fast to dismantle, and except for the bolt holes, it is relatively less time-consuming to recover the components. [30]

The main purpose of this part is to provide a small project as an example to illustrate how to design and apply re-used steel structure components. Environmental impacts of the project will be discussed during its lifecycle, and the calculation method illustrated in section 1.3.1. will be used accordingly.

4.1 STEEL STRUCTURE PROJECT

We are assigned to design a storage hall from the steel structures, and columns and beams could be chosen from HEA- or IPE profiles. There are total of 12 parallel columns, 6 on each side, and the width-span between two columns is L=7,2 m c/c. The span between columns on the long-side is K=6m. The height of the building is h=8,4m, and the roof slope is considered 1:10. Foundation of the columns to be case-in-place RCC concrete and columns are rigidly installed on them. Roof and walls are covered by steel corrugated sheets, and to address stiffening of the structure, diagonal steel rods are considered inside direction as in figure 6.

Besides, the calculation is based on Eurocode (EN 1990, EN 1991, EN 1993) and the structure location is in Tampere. This case study aims to apply the principle of design-for-deconstruction

(DfD) to the project, and analysis how the main components can be later detached and re-used accordingly.

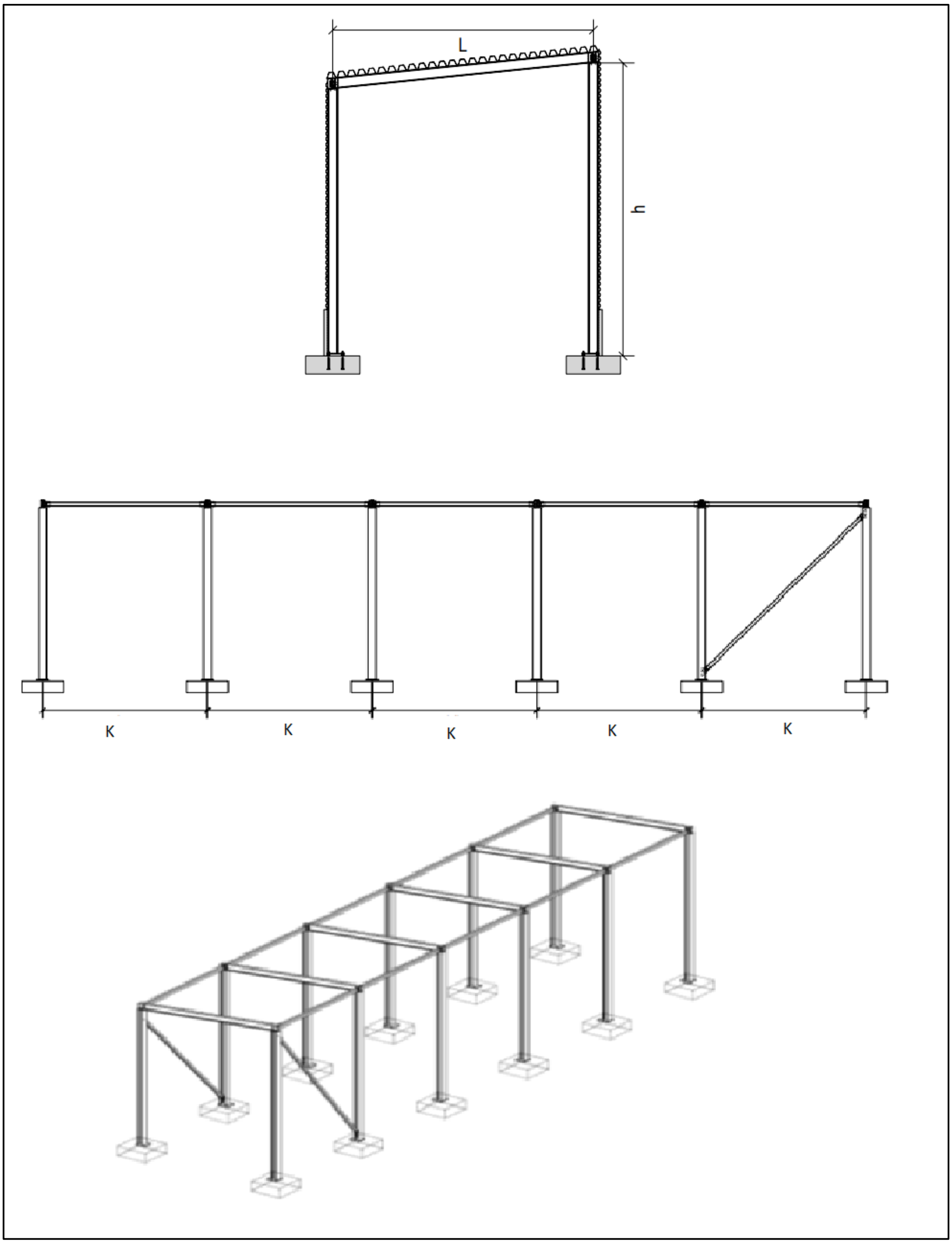

Figure 6: *Main component of the structure.*

4.1.1 APPLICATION OF THE DfD PRINCIPLES ON PROJECT

Although the original intention of this building was not to design for deconstruction, the design-for-deconstruction (DfD) principle-application will be applied. Firstly, the structure has a simple and regular shape which is a rectangle, suited for storage space. It allows columns to be arranged symmetrically, and subsequently helps proper load distribution and easy connections' installation on steel members. Ab irregular structure shapes provide significant challenges for the steel components dismantling, sorting, and re-using. An irregular structure shapes have various lengths, and in contrast re-using requires repeatable design, and in that case, a standard length for a component is necessary.

Secondly, bolted connections are used extensively. The number of bolts, plate sizes, and orientation varies by connection types, however, all of them can be easily deconstructed. There are welded connections on this steel structure too, especially at the column-footing connections. Thirdly, due to the small size of the building, main steel components have yield strengths of 355 MPa, and there are not many varieties of steel grades and sections. All the columns and most of the beams have same length, and this is beneficial if they are re-used. Considerations of various steel grades, sections, and sizes will complicate re-using of the materials.

And lastly, adaptability is another main factor for re-using a whole building or part of it. For example, the project snow load is considered according to Tampere city of Finland about 2kN/m^2. Now if we want to re-use this building in another area of Finland with a heavier snow load standard at the end of its lifecycle, re-designing would be a challenging issue.

Steel structures made of various components, which all of them are important for re-using purposes at end of their lifecycle. Each main component of the steel structure will be discussed accordingly.

4.1.2 COLUMNS

The columns are HEA 320 steel profiles based on calculation, and they are connected by bolt-, and anchor bolt connection at the top and bottom parts, respectively. the bolts are cast into the concrete foundation with four holding down bolts, in order not to be detached. A 30mm thick base plate is fixed by 4 anchor bolts on the foundation, and the profile is welded on the baseplate. In addition, baseplate stiffeners are also considered as in figure 7.

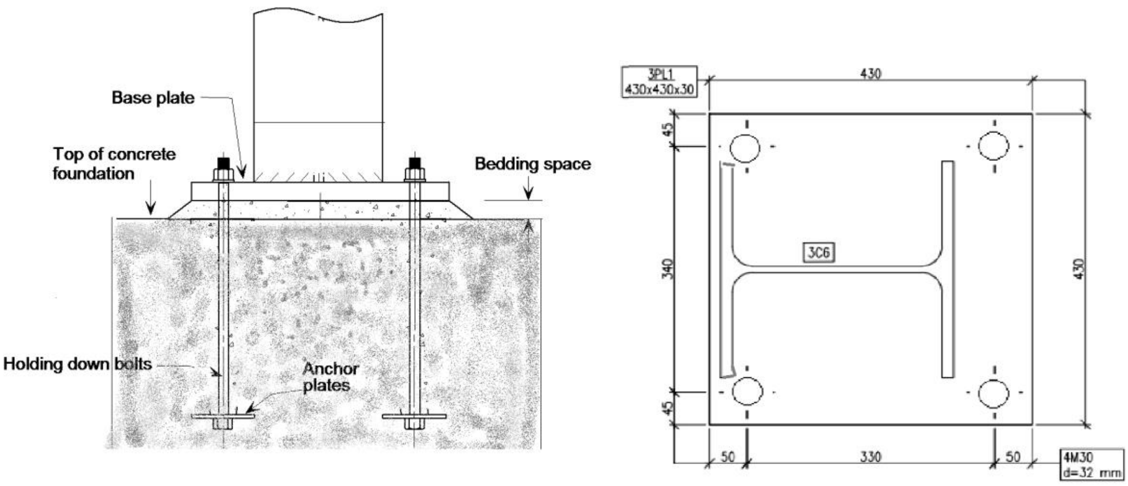

Figure 7: Column-footing connection of the project.

Another option would be to provide bolt holes at the bottom part of the profile for connection, in order not to consider welding on the baseplate, stiffener, or any other types of connection plats for column-footing. Higher strong structural connections are possible due to higher strength bolts. Both ordinary and high-strength bolts are easy to dismantle, which is appealing for design-for-deconstruction (DfD) method [32]. However, creating holes itself weakens the member, and increase workload.

The columns maintenance is also an important factor for keeping them intact through their lifecycle and end-of-life re-use. Proper coating and use of good quality material should be considered. Utilities and other system services should be installed with minimum damage to the columns and easily accessible. Exterior or interior panel, separation walls, and in this case, corrugated stainless steel sheet installation on columns must be easily replaceable and detachable. Columns and other main structures must be self-supporting with less possible complex connections. This avoids damage and saves time during structure demolition. [30, p. 48]

4.1.3 BEAMS AND BRACES

The beams are HEA 260 steel profiles based on calculation, and connections of beams and columns are all considered by bolts at the upper part of the structure as in figure 8. Columns have a relatively small span in this project, and ordinary bolted connections are supportable. Considering a proper length is important for reusing beam components. Longer lengths may not be supported easily by bolted connections. In this project, there is only one type of main beam HEA260, all with equal lengths of 7513mm, and horizontal braces of steel hollow section (130x130x6) mm of equal lengths of 5640mm. There are two diagonal braces at the long side of the structure with the length of 10223mm. All braces are connected by gusset plate connection by bolts, and these types of connections are very common in steel structures.

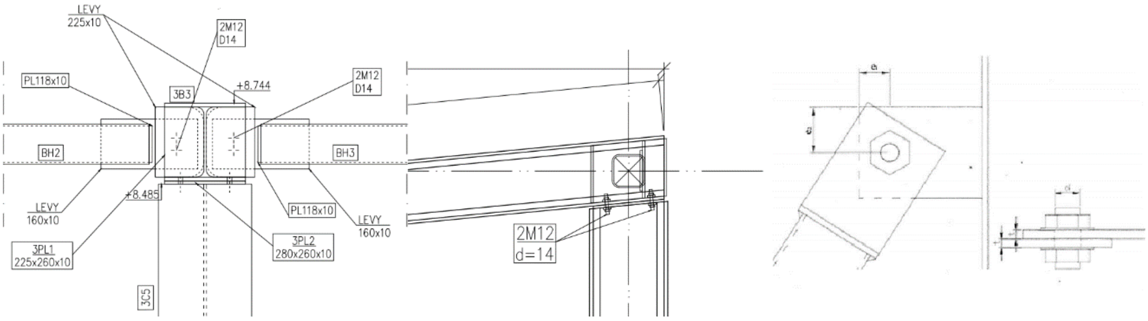

Figure 8: Brace connection of the project.

Connection plates have different dimensions based on design, and where connection requires to uphold greater forces, plates are bigger, and have more bolt holes accordingly, such as the connection of column, beam, and braces where a steel plate of 3PL2(280x260x10) mm is considered on top of the column. A designer must consider the idea, that a small project like this has various components with different needed dimensions, and to facilitate re-using them, common members should be applied as much as possible. Lastly, all the points mentioned and recommend in the column section are applicable for beams and braces regards to the DfD principle.

4.1.4 STEEL CORRUGATED SHEETS

In this structure corrugated sheet is considered for the structure sides' cover as a none load-bearing panels. However, roof panels are designed to resist at least snow load. Generally, load-bearing corrugated sheets can be used for the wall and roof with a span-length capacity of almost nine meters. Load-bearing sheets are relatively complicated to redesign for re-use purposes because of overlap joints holes in the web of sheets [5, p. 62]. Large sheets can cover a large span, use fewer fasteners and joints. In addition, using screws would improve for possible re-use of both load-bearing and none load-bearing sheets. Basically, design-for-deconstruction (DfD) principle suggests considering standard side overlap and larger sheets with the fastening of screws against support. It is also important that standard fastening spacing without damaging the integrity of the sheets applies on the sheets. [5, p. 63].

4.2 LIFECYCLE ASSESSMENT CALCULATION OF THE PROJECT

In this section, we are going to calculate the potential environmental impacts, especially CO2 of global warming (GWP) of the building's main components according to the method mentioned in section 2.2.1. All lifecycle stages are included in this assessment as well as the supplementary module D stage of the structure. The relevant properties of each component are listed in Table 2.

Table 2: Properties of the project's main components.

Component	Type	Weight (Kg/m)	Length (m)	Amount (Units)
Pillars	HEA 320	97,60	8,40	12
Beams	HEA 260	68,20	7,51	6
	HS	23,06	5,64	10
Braces	HS	23,06	10,22	2
Connections	steel plates(430x430x30)	43,54	-	12
	steel plates(260x260x10)	5,31		20
	Bolts M24 Grade 8.8	110kg/1000Pieces		
Foundation	RCC (600 x 600 x 500) mm	-	-	12
	Steel bars (D = 20mm)	2,47	12m/f	12
	Anchor bolts (D= 25mm)	2,35	4 x0,15	12

Below Table 3 indicates the amount of steel and concrete materials used in the project. The material estimation includes the project's main steel structure and column-footings.

Table 3: Total amount of steel and concrete in the project.

Component	Type	Amount	Section	Total
Pillars	HEA 320	9233,3 Kg	12330,9 Kg	14612,5Kg
Beams	HEA 260	3097,6 Kg		
	HS	1300,6 Kg	1771,9 Kg	
Braces	HS	471,3 Kg		
Connections	steel plates(430x430x30)	224,7 Kg	546,7 Kg	
	steel plates(260x260x10)	27,6 Kg		
	Bolts M24 Grade 8.8	30 Kg		
Foundation	Steel bars (D = 20mm)	213,4 Kg		
	Anchor bolts (D= 25mm)	21 Kg		
	Concrete	2,2 m^3 + 5%		2,3

We are going to next describe indicators for the components' recourse use according to Table 4. As there are various data available for environmental parameters regards to the steel industry, we are using data mostly based on provided Environmental product declaration (EPD) of steel industries of Northern Europe. Table 4 indicates environmental parameters for structural hollow sections, steel sections, and steel plates for the components HS beams and braces, columns and beams, and steel plates, respectively [33]. Steel bars, bolts, and anchor bolts are considered the same parameters as steel plates.

According to EN 15804 6.2.1, A1-A3 is the most significant stage of the product and compulsory for declaration of its environmental impacts [4, P16]. In steel material, about 70% of CO2 produces in this stage [35, P65]. Environmental impacts of B1-B7 stages are mostly ignored in the steel industry as it has a relatively low contribution regard to greenhouse gases. As our project is small, it will have minimum impact on the overall lifecycle assessment. End-of-life C1-C4 and supplementary stages D will be covered.

RCC column footings' parameters are acquired from ready-mixed concrete EPD for the A1-A3 stages [34]. We assume the 28-day compressive strength of concrete is a maximum of $25\ \mathrm{MPa}$, which is typical for such a project, so we consider the provided parameters in Table 4.

Table 4: Parameters describing environmental impacts 1-ton steel and 1 m^3 concrete & [34].

Parameters	**Stage (Kg)**	**Beams and columns**	**HS beams and braces**	**Steel plates, bars, and bolts**	**RCC footing (Kg/m^3)**
GWP Global warming potential (kg CO_2)	A1	1,490	2,790	2,560	214,41
	A2	0,019	0,021	0,026	
	A3	0,194	0,181	0,177	
	A4	0,032	0,045	0,038	0
	A5	0	0	0	0
	B1-B7	0	0	0	0
	C1	0,028	0,028	0,028	0
	C2	0,017	0,017	0,017	0
	C3	0,002	0,002	0,002	0
	C4	0,0008	0,0008	0,0008	0
	D	-1,26	-1,43	-1,42	0

We have calculated projects' material quantities in Table 3 and using indicators from Table 4, we calculate category indicators for every module. Then, based on the provided data, we are going to calculate each module through its lifecycle stages accordingly to equation (1). The result will be indicated in Table 5. [13, p. 44]

Table 5: Parameters describing environmental impacts of various components.

Parameters	Stages (Kg)	Unit	Beams and columns	HS beams and braces	Steel plates, bars, and bolts	RCC footing (Kg/m^3)
GWP Global warming potential	A1	kg CO_2	18373,04	4943,60	1399,55	493,143
	A2	kg CO_2	234,29	37,21	14,21	
	A3	kg CO_2	2392,19	320,71	96,77	
	A4	kg CO_2	394,59	79,74	20,77	0
	A5	kg CO_2	0,00	0,00	0,00	0
	B1-B7	kg CO_2	0,00	0,00	0,00	0
	C1	kg CO_2	345,27	49,61	15,31	0
	C2	kg CO_2	209,63	30,12	9,29	0
	C3	kg CO_2	24,66	3,54	1,09	0
	C4	kg CO_2	9,86	1,42	0,44	0
	D	kg CO_2	-15536,93	-2533,82	-776,31	0

Below Table 6 will indicate the LCA result for the global warming potential (GWP) of the project through various lifecycle stages.

Table 6: Parameters describing environmental impacts of the project at various life cycle stages.

Parameters	Stages (Kg)	Unit	Projects' main components. All project materials
GWP Global warming potential	A1	kg $CO_{2\ equiv}$	25209,34
	A2	kg $CO_{2\ equiv}$	778,85
	A3	kg $CO_{2\ equiv}$	3302,82
	A4	kg $CO_{2\ equiv}$	495,10
	A5	kg $CO_{2\ equiv}$	0,00
	B1-B7	kg $CO_{2\ equiv}$	0,00
	C1	kg $CO_{2\ equiv}$	410,19
	C2	kg $CO_{2\ equiv}$	249,04
	C3	kg $CO_{2\ equiv}$	29,30
	C4	kg $CO_{2\ equiv}$	11,72
	D	kg $CO_{2\ equiv}$	-15536,93

4.3 CONCLUSIONS

The project can be a good example of a re-use project due to its simple design and regularity. The distance among main components e.g., columns is regular with the same cross-section and material grade. Most of the joints are bolt connection, except for base plates which are welded. Beams are also well distance and have regular lengths. Corrugated sheets are installed mostly by screws, which are easily replaceable and renewable. Most of the structure can be easily dismantled without hard effort, and the whole structure can be transferred and reconstructed in a new place. However, the bigger project become more complex to design for deconstruction. What we can learn is to replicate small structures as modulus and turn them for larger project design and application.

The LCA calculation of the project indicates a total production of $2{,}16 \cdot 10^4\ KgCO_{2\ equiv.}$ of CO_2 through all the lifecycle stages of the project. A huge percentage of the produced emission belongs to module (A1-A3), which belongs to the raw material preparation stage. However, a significant reduction of emission about $1{,}55 \cdot 10^4\ KgCO_{2\ equiv.}$ [Stage D, Table 5] can be achieved by potential re-using of the project material in the future. This shows such a project can reduce 78% of its impacts on global warming through re-usability.

5. SUMMARY

The circular economy could provide the platform for sustainable development in construction, especially in steel structures. We have also mentioned that the steel industry could have an impact on reducing greenhouse gases, especially CO_2. It can be achieved by the conversion of coal-based blast furnaces (BF) to electronic arc furnaces (EAF). A simple LCA calculation shows that such a conversion could reduce the amount of CO_2 by up to 50%. Other methods are already in progress such as using ultra-low carbon dioxide steelmaking (ULCOS) and hydrogen from iron ore reduction. We have discussed these points in the recycling steel material. However, the re-usability of steel frames may have better positive impacts on the environment.

Steel frames are inherently recyclable and re-useable repeatedly as the material properties do not degrade fast. We can re-use a steel frame if we could consider it as early as the design stage. It is important to apply the principle of design-for-deconstruction (DfD) and assess lifecycle stages through LCA calculation or other similar tools. We have illustrated a project as an example and showed that small projects are much easier to do so. However, bigger, and more complex projects can also be done, by considering the small project as a module. All barriers regard to this issue are resolvable they are well managed.

We have also provided the lifecycle assessment of a project to illustrate its relative environmental impact. We have done our calculation on realistic pre-determined scenarios provided according to EN 15978. The unite data used for these scenarios are obtained from steel producers' product declarations (EPD) as indicators. Such a small steel structure has equivalent $2,16 \cdot 10^4\ Kg$ production of CO_2. However, the potential recyclability and re-usability of steel frames can reduce CO_2 impact up to 78%.

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