Description of Steel Frame re-use process and its environmental impact

Case: Relocation of steel frame warehouse in Lappeenranta region

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Abstract

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Abstract

The first aim of the thesis work was to describe the inspection of disassembled elements of the steel frame and create a template for inspection report. It was done on the basis of a case presented by TTV-kiinteistöt Oy. The considered case was “Relocating a steel envelope of a one-storey warehouse”.

The automated excel sheet was created suitable for dimensional tolerance inspection report for CFRHS profiles and I-beams. It can be requested from the author of the thesis.

The second aim of the research was to calculate and compare the environmental impact of newly manufactured warehouse with relocated warehouse. The impact was represented by global warming potential in CO_{2eq}.

The results show that the decision to reuse steel can give significant reduction in CO_2 emissions, because the manufacturing of new steel has considerably high negative environmental impacts when compared to transportation and construction.

Keywords

Steel reuse, envelope relocation, steel frame inspection, dimensional tolerance, global warming potential

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List of terms

Envelope – the enclosure around the building that separates the enclosed space from the external environment and provides a range of structural and building physics functions.

Recycling – Process of converting waste materials into new materials and products; recycling steel involves re-melting of scrap to form new semi-finished products.

Reuse – Use of old components with little or no reprocessing, largely in their original form; they may be reused for the original function, or repurposed.

1 Introduction

This thesis work is the case study of steel envelope relocation of warehouse performed by TTV-kiinteistöt Oy. The purpose of this thesis is to describe the process of inspecting elements of the disassembled steel frame and calculate the environmental impact difference between manufacturing new elements and reusing the old frame through relocation.

Part of this research will describe the methods of steel frame inspection. The elements of the envelope which will be relocated should be inspected and tested before they are suitable for reuse. An automated excel inspection sheet will be created as a result of this thesis work to ease the complex inspection procedure.

The second part of the thesis will include the analysis of overall carbon dioxide (CO_2) emissions during the relocation process and erecting a structure from raw materials. Methods of calculating the emissions will be provided and the question of expediency of frame relocation will be addressed.

As a result of this research the following questions will be answered:

- How elements of steel envelope should be inspected?
- How much CO_2 emissions were saved due to steel envelope relocation?

2 Steel envelope reuse

2.1 Steel as building material

Steel is a fascinating building material, widely used in various construction all over the world. Its popularity can be explained by the benefits it provides. Steel is durable, flexible, sustainable and a high-strength material.

Steel's durability allows it to better resist weather conditions and fire hazards. Therefore, the lifespan of the steel frame buildings is really high.

Another advantage of steel frame buildings is its ease of modifications. Steel framed buildings can be expanded, reinforced or repaired in a short period of time.

Figure 1 Walt Disney Concert Hall, California, USA (Photo: Nash Photos 2016)

Stell is sustainable material, because up to 99% of steel is reused or recycled at the end of its lifecycle. Recycled steel then can be used in manufacturing new elements. Moreover, the methods of manufacturing are constantly developing to minimize environmental impact and raw material consumption. (British Constructional Steelwork Association a.)

Steel structures have highest strength to weight ratio compared to wood and concrete. Less material is needed, resulting in thinner and lighter frames. It opens the possibility for more enthusiastic and modern designs.

2.2 Structural steel shapes

Steel comes in a variety of different shapes due to its stiffness and ductility.

Figure 2 Types of structural steel sections (Image: depositphotos)

The most common profiles are:

- Steel angles or L-shaped cross-section. These elements have wide application, they can be used as wood connectors, shelfing and structural reinforcement.
- Hollow sections. Various steel tubes are widely used as they consume minimum of material making light-weight structures that consume little material. At the same time these elements retain high structural characteristics. Application varies from tubes to columns and beams.
- I-beams and H-beams. Steel beams have wide flanges to provide bending resistance and bigger load distribution. I-beams can be used to support floors in residential buildings, H-beams have bigger strength capacity and often used as foundations for buildings.

All of these sections and many others are used in various steel elements that make up a frame of a building.

2.3 Components of steel envelope

Steel envelope serves primary functions of the building. It prevents free temperature flow inside, protecting people and equipment. To prevent this flow, the perimeter of the building should be protected from outside climate impact. Therefore, we need walls, roof and floor as well as any embedded elements (doors, windows etc.). Another purpose of the envelope is to give the final decoration to the façade and sometimes even interior. The exterior is made with cladding (i.e. sandwich panels, wooden planks).

All of the elements mentioned above act as a load, which should be transferred to foundation through purlins, rafters, trusses, beams and columns. These elements together form a frame of the building. They carry the loads from the structural elements (dead loads), from people and furniture (live loads) and from snow, wind and sometimes seismic actions (environmental loads). (British Constructional Steelwork Association b.)

On Figure 3 you can see the typical structure of one-story building supported by steel frame. Such buildings are usually used as warehouses or production factories.

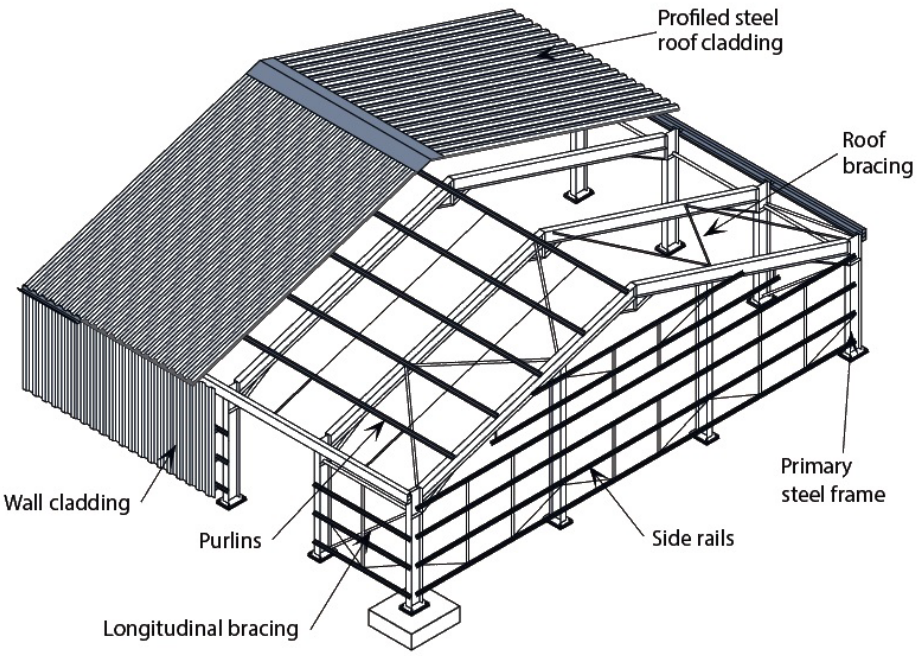

Figure 3 Main components of steel envelope (Coelho et al. 2020, 3)

2.4 Reuse and recycling

Steel has great sustainability due to its ability to be reused and recycled. It is easier to see how effective the steel is used when we compare it to other building materials.

While most concrete and wood elements are downcycled or disposed at the end of their lifecycle – only 1% of steel goes to landfill. And 13% of steel products are reused, which has much greater positive environmental impact than recycling. (Hradil et al. 2014, 23)

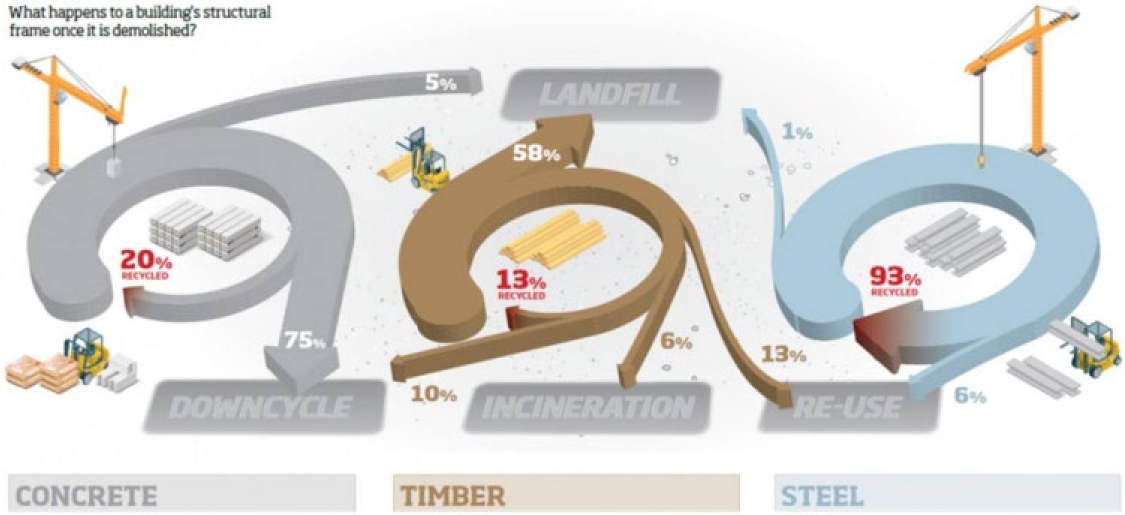

Figure 4 End-of-life scenarios of concrete, timber and steel buildings (Hradil et al. 2014, 23)

It means that once the steel was manufactured from raw materials it will be reused and recycled for many years, allowing to save a great amount of CO2 emissions from manufacturing new steel.

It is worth mentioning that when we talk about steel, there is a big difference in environmental impact between reuse and recycling, reuse being more environmentally friendly and energy saving process.

Even though only 6% of steel is reused compared to 93% being recycled – industry develops in direction of design for deconstruction (DfD), which inevitably rises the reuse rate.

2.5 Design for deconstruction

It is important for future reuse to think beyond easy and low-budget construction. According to Hradil (2014, 50) every participant of construction project can influence the reusability of the structure. The biggest contribution to reusability can be achieved by Architects and Engineers, as they decide how the structure will look and what components will be used to achieve the desired appearance.

Design Principles	Owners	Architects	Engineers	General Contractor/ CM	Specialty/ Subcontractors	Fabricators/ Manufacturers	Suppliers
1 Design for prefabrication, preassembly and modular construction		High	High	Medium	High	High	
2 Simplify and standardize connection details		Medium	High	Medium	High	High	Medium
3 Simplify and separate building systems		High	High	Medium	Medium		
4 Consider worker safety during deconstruction & construction		Medium	Medium	High	High	Medium	Medium
5 Minimize building components and materials		High	Medium	Medium	Medium	Medium	Medium
6 Select fittings, fasteners, adhesives and sealants that allow for quicker disassembly and facilitate the removal of reusable materials		Medium	High	Medium	High	High	High
7 Design to accommodate deconstruction logistics		High	High	Medium	Medium		
8 Reduce building complexity	Medium	High	Medium		Medium		
9 Design to reusable materials	Medium	High	Medium	Medium	Medium	Medium	Medium
10 Design for flexibility and adaptability	High	High	Medium				

High relevance
Medium relevance

Table 1 Possible impact of all parties involved in construction project (Hradil et al. 2014, 51)

Here are the most common principles for deconstruction that can be used by Designers according to steel construction encyclopedia for UK (2022) are:

- Use bolted connections in preference to welded joints to allow the structure to be dismantled during deconstruction
- Use standard connection details including bolt sizes and the spacing of holes
- Ensure easy and permanent access to connections
- Minimize the use of fixings to structural steel elements that require welding or drilling holes
- Use long-span beams as they are more likely to allow flexibility of use and to be reusable by cutting the beam to a new length.

3 Case study: One-storey warehouse inspection

3.1 Description of the case

This research was suggested by TTV-kiinteistöt Oy and it concerns steel envelope relocation of warehouse in Lappeenranta region. The relocated elements are I-beams; CFRHS profiles and PAROC panels.

The warehouse was erected in 2013 and decision to move the building was made due to economic reasons.

Figure 6 represents the structural elements of the steel frame that will be relocated. In this case cold formed rectangular profiles make up 90% of relocated steel elements, they are highlighted with blue. Green elements are the I-beams used in the steel frame. The red elements are the ones that were only existent on the old drawings, although they were not constructed in the original building.

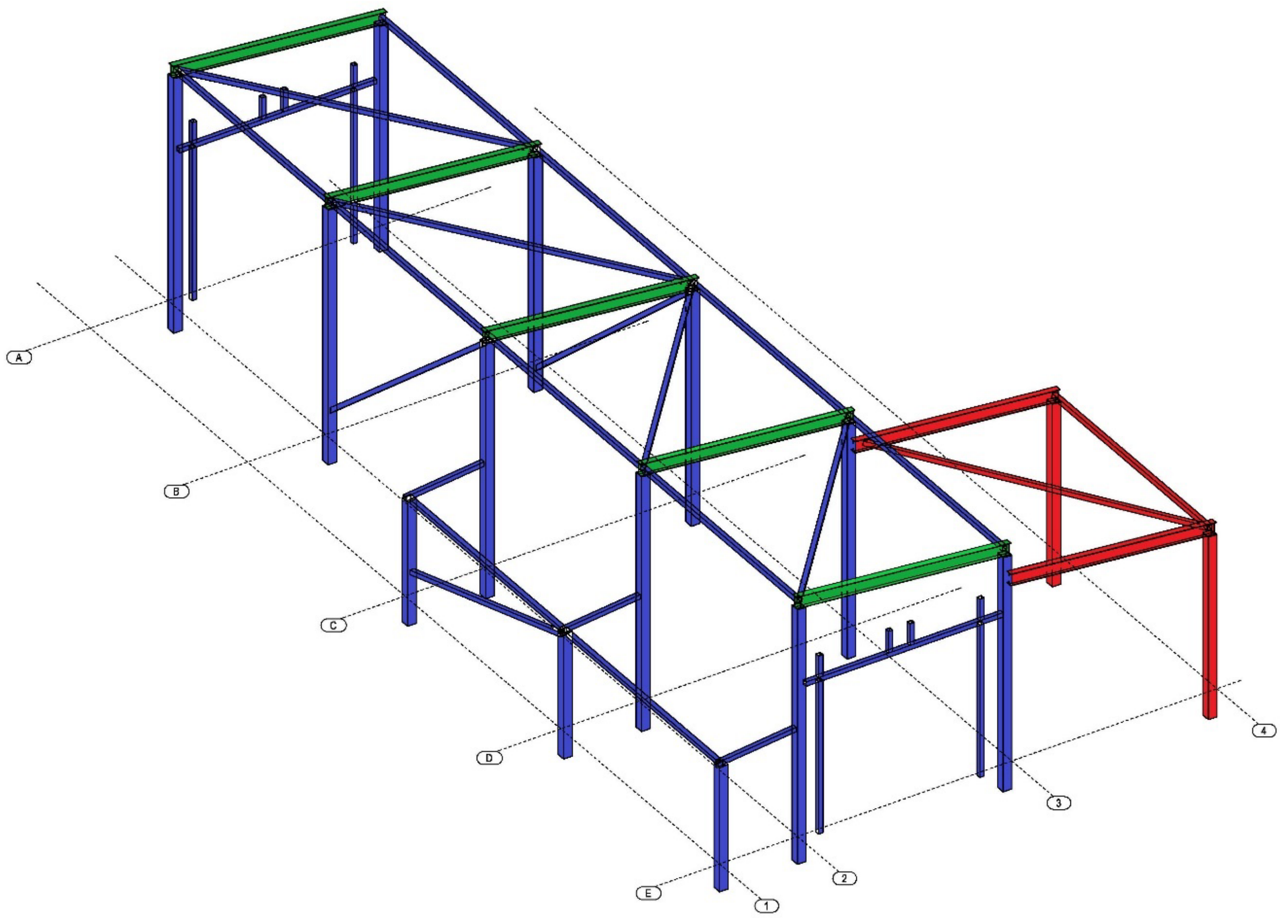

Figure 5 3D representation of steel frame (source: Researched case)

The research goals that will be achieved in this section are:

- listing the inspection requirements and methods that are used to assess the quality of elements
- developing an excel sheet that can be used as a framework for steel one-story building dimensional inspection report

3.2 General description of building reuse process

Figure 7 shows the whole evaluation and inspection process. As it can be seen, the first step for reusing a structure is to determine if steel components of the structure can be re-used. Only after certification was obtained company can get demolition permission and begin the site work.

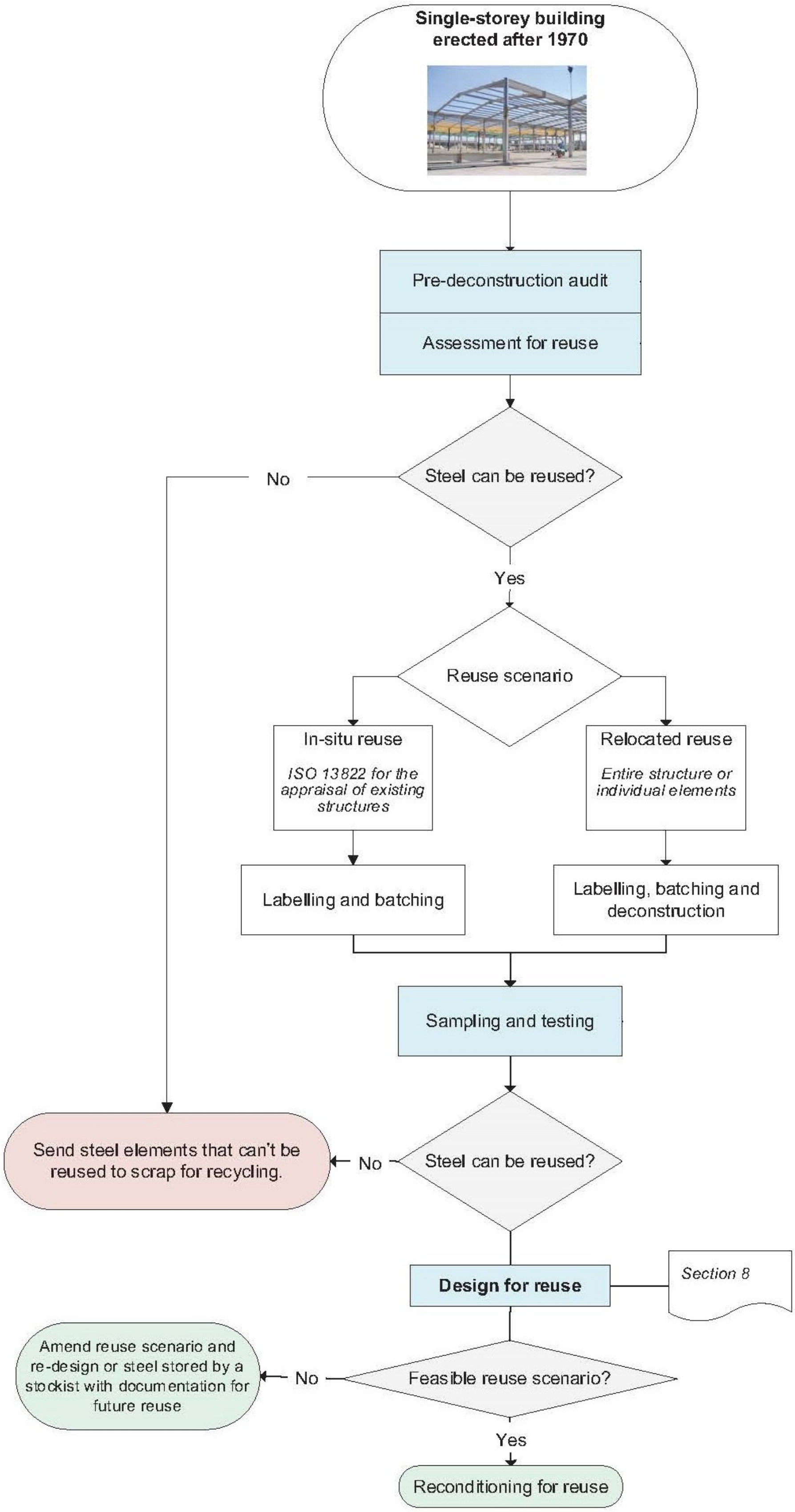

Figure 6 Overlook at the process of reclaiming structural steel elements (Coelho et al. 2020, 41)

The Guidelines for waste audits (2018) states that there are 4 main stages during the Pre-deconstruction audit:

1. Review of building documentation (desk study). It concerns collection of all the relevant documents on the structure that will be reused. The primary documents that should be obtained should include: erection date of the building; technical drawings and architectural plans; history of maintenance and renovation; list of dangerous substances; local waste facilities.

2. Field survey. It concerns analyzing the obtained documentation and comparing it to site situation. During this phase non-destructive and destructive methods can be used to assess the structure's correspondence with collected drawings.

3. Inventory of structure. All elements from furniture to columns should be inventoried in order to ease the waste management process. During this stage the thought should be given to how the waste management could be organized.

4. Advice report for waste management. In this report the whole audit can be summarized to give recommendations for people who will perform the demolition process.

Assessment for reuse is performed in order to identify the element's certification if it is possible and assign the class to the steel materials.

According to European recommendations (Coelho et al. 2020, 51) here are the main CE marking classes:

- If it is possible to find original certificates, which show material's performance characteristics and quality assurance certificates – class A is obtained for the steelwork. This means that steel can be used for structures with any service class (CC1, CC2, CC3).

- Class B is given to the structure in case if no certificates were available before assessment and the steel was re-certified through tests. Class B steelwork is appliable to all service classes.

- Class C is the case when no detailed testing was performed and certificates are not available. This steel elements can be only used for service class 3 (agricultural buildings, fencing).

When the steel class was identified for the elements – they can be inspected to check if they are suitable to be reused or if they should be recycled. The inspection process is one of the interests of this research and it will be described in Section 3.3.

After elements were inspected – the structural design for new structure and reused elements should be performed. The European Recommendations for Reuse of Steel Products in Single-story Buildings (2020, 111) state that usually the structures that use reclaimed steel elements can be designed in the same way that the ones with new steel. However, some precautions should be taken and the source mentioned above provides these recommendations. For example, if the frame is relocated it usually has the same loads applied to it. However, if these loads change – the calculation should be performed again to check that given sections of the elements can still withstand the new loads.

3.3 Field survey and risk evaluation

When the warehouse frame in Lappeenranta was inspected, it was discovered that part of the frame that was on every architectural and structural drawing was not erected. That is why the field survey should be done simultaneously with the desk study of the structure. Otherwise, there is a risk of misinterpreting the structure's composition and some problems might stay unnoticed.

After completing the filed survey and settling all discrepancies between drawings and erected structure– risk evaluation of the frame must be performed. It means that we should analyze the steel frame as a whole and locate potential risks in the structure. This step is significant and might show some problems that could put the whole structure at risk.

If there are any places in the structure that could be under risk during the exploitation of the building, for example there was a weather exposed load-bearing connection – we need to inspect it and based on the inspection report eliminate any risks.

In the studied case the risk evaluation showed that the special attention should be paid to the connection between columns and foundation. This was a rigid connection which was located underground. It means that there was a risk of weakening of the weld splices, which potentially could lead to the failure of the structure.

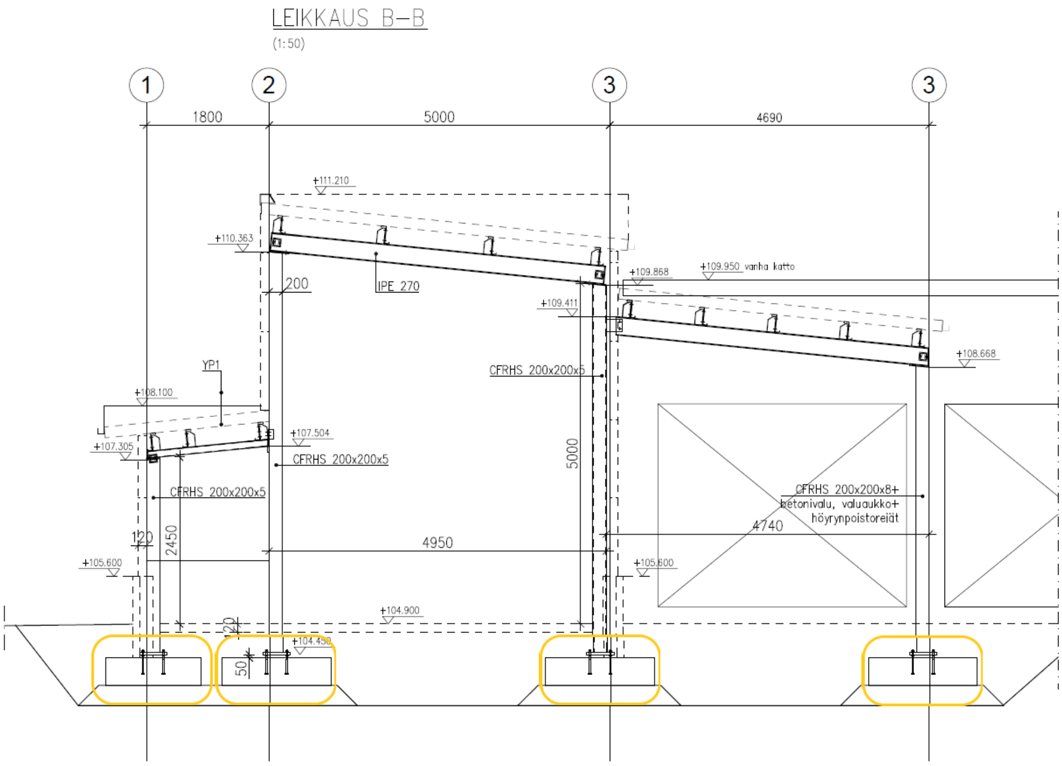

Figure 7 The connection that bears potential risk (Source: Researched case)

The ultrasonic scanning of the weld splices was performed in this case and some welds were repaired after inspection report, which is provided in Appendix 1.

3.4 Inspection of dimensional tolerances

Disassembling the frame is followed by checking the elements accordingly to the standards and making sure that they can be reused. Usually, it is important to check that reclaimed element is not corroded, change of original dimension is within tolerance and material quality is acceptable (Coelho et al. 2020, 101).

In the case of the warehouse in Lappeenranta the dimensional tolerance check was not performed due to the results of the field survey. All of the elements were in a good shape and there was no need to perform the inspection. However, in case of any potential defects related to dimensional integrity of the elements – the inspection of dimensional tolerances should be conducted and the inspection process is described in this section.

Different elements have their own standards for reusability evaluation. Two main standards that exist for every steel element are Dimensional and Tolerance standard and Material Quality standard. The table below provides the needed standards for the main steel elements used in construction.

<table>
<tr><th rowspan="2">Form</th><th rowspan="2">Dimensions</th><th rowspan="2">Tolerances</th><th colspan="2">Material quality</th></tr>
<tr><th>Non-alloy steels</th><th>Weathering steels</th></tr>
<tr><td>I and H sections</td><td>EN 10365</td><td>EN 10034</td><td rowspan="9">EN 10025-2(a)
EN 10025-3
EN 10025-4</td><td rowspan="9">EN 10025-5(b)</td></tr>
<tr><td>Hot-rolled taper flange I sections</td><td>EN 10365</td><td>EN 10024</td></tr>
<tr><td>Channels</td><td>EN 10365</td><td>EN 10279</td></tr>
<tr><td>Rolled asymmetric beams</td><td colspan="2">See manufacturers' information.</td></tr>
<tr><td>Angles</td><td>EN 10056-1</td><td>EN 10056-2</td></tr>
<tr><td>Rolled Tees</td><td>EN 10055</td><td>EN 10055</td></tr>
<tr><td>Fabricated sections and member bow imperfections</td><td>—</td><td>EN 1090-2</td></tr>
<tr><td>Plates (reversing mill) (c)</td><td>—</td><td>EN 10029</td></tr>
<tr><td>Plates (cut from coil) (c)</td><td>—</td><td>EN 10051</td></tr>
<tr><td colspan="5">(a) Steel grades S235, S275, S355 and S450. The steel grades S235 and S275 may be supplied in qualities JR, J0 and J2. The steel grade S355 may be supplied in qualities JR, J0, J2 and K2. The steel grade S450 is supplied in quality J0.
(b) Steel grades S235 and S355. The steel grade S235 may be supplied in qualities J0W and J2W. The steel grade S355 may be supplied in qualities J0W, J0WP, J2W, J2WP and K2W.
(c) The scope of EN 10029 covers plates of 3 mm up to 250 mm rolled in a reversing mill process, whereas EN 10051 covers plates up to 25 mm de-coiled continuously hot-rolled uncoated flat products.</td></tr>
</table>

<table>
<tr><th>Form(a)</th><th>Dimensions and tolerances</th><th>Material quality</th></tr>
<tr><td>Hollow sections (hot finished)</td><td>EN 10210-2</td><td>EN 10210-1</td></tr>
<tr><td>Hollow sections (cold formed)</td><td>EN 10219-2</td><td>EN 10219-1</td></tr>
<tr><td colspan="3">(a) Hollow sections for use in constructional steelwork (both hot finished and cold formed) are supplied in steel grade S235 in quality JRH, steel grade S275 in qualities J0H and J2H, and S355 in qualities J0H, J2H, and K2H.
Note: Selection of either EN 10210 or EN 10219 specifies whether structural hollow sections are to be hot finished or cold formed. Hot finished structural hollow sections to EN 10210 cannot be directly replaced with cold formed structural hollow sections to EN 10219 as the properties do not correspond directly.</td></tr>
</table>

Table 2 Standards used for inspecting the steel elements (Coelho et al. 2020, 58)

The main purpose of this thesis was describing the inspection of dimensional tolerances, but it is also important to mention that material quality standards describe the material performance of the elements. They can be used to check the mechanical properties, chemical composition, technological properties, delivery conditions, check the weld splices and other characteristics (EN-10219-1:2006, 2).

The considered one-story warehouse has 3 types of elements to inspect:

- CFRHS profiles (Cold formed rectangular hollow section). Used as columns, lintels and bracing

- I-beams. In relocated warehouse studied in this research, they are used as load-bearing beams to support the roof
- PAROC elements. These sandwich panels are used to create an exterior façade and provide thermal insulation of the structure along with additional bracing

According to European Recommendations (Coelho et al. 2020, 198) to measure the dimensional characteristics of the elements we can use Vernier callipers, micrometres, three-dimensional laser scanning, ultrasonic measurements or other instruments. The preferable instrument and tolerances are not specified in the standard.

We need to look at all of these elements separately, because characteristics that need to be inspected vary significantly depending on element and its section. That is due to unique shape, purpose of the envelope part and the loads it is subjected to.

3.4.1 CFRHS profiles

There are two standards which describe the tolerances and material quality for cold formed rectangular hollow section profiles. Main documents that should be used during assessment are:

1. European Standard EN 10219-1:2019 – describes the material quality.
2. European Standard EN 10219-2:2019 – describes tolerances and dimensions.

The purpose of this research is describing the methods of inspecting shape and size of disassembled elements and criteria to check if the elements are suitable for re-use. For this reason, we will take a closer look at the second document – EN 10219-2.

The following parameters are checked when we consider reusing cold formed hollow sections:

- Outside dimensions
- Thickness
- Squareness of the side
- Length
- Concavity and convexity
- External corner profile
- Twist

- Straightness
- Mass per unit length

EN 10219-2 standard provides us with tables, which show the tolerances for the elements. The tables are very convenient to use and contain all the information needed for inspection result analysis. Tables are attached in Appendix 2.

In order to check these characteristics, firstly, we need to take all the measurements. To conduct faultless measuring, it is important to read instructions that are provided in standard (EN 10219-2, Section 7 “Measurements of size and shape”).

3.4.2 I-beams

I-beam is element with standard dimensions which can be checked in EN 10365. The standard for I-beam tolerance inspection is EN 10034 and its material quality can be checked in EN 10025.

After labeling structural elements and disassembling the structure each element should be measured and its dimensions should be compared to the original ones, obtained during pre-deconstruction audit. The following tolerances should be checked according to the standard:

- Section height
- Flange width
- Web thickness
- Out-of-squareness
- Web off-center
- Straightness
- Mass
- Length

Additional information and tables with tolerances can be found in Appendix 3.

3.4.3 PAROC panels

The standard that is used to check the dimensional tolerances of the sandwich panels is EN 14059. According to the Technical guide (PAROC Panel system 2022, 23) maximum deflection for external wall panels is L/100.

According to European Recommendations for Reuse of Steel Products in Single-Storey Buildings (2020, 79) there are also characteristics apart from dimensional properties that can be checked prior to reuse. It is important to emphasize that it is not mandatory to check these characteristics, as EN 14509 is a standard for the factory testing of the panels. These recommendations can be used if there is any doubt about the quality and it needs to be checked, or if it is specified by the commission or other party.

Few mechanical parameters that can be tested (EN 10459):

- Tensile strength. From 3 up to 10 panels should be taken and tested. If the tensile strength value is 10% lower from original value – only 1 more panel shear strength test is required. If the tensile strength is within the tolerance – no further mechanical testing is required.
- Shear strength. One sample is tested if the tensile strength is OK. From 3 to 5 samples should be tested if tensile strength test was failed.
- Durability (optional)
- Compression (optional)
- Bending moment (optional)

Along with mechanical and dimensional tolerances we can also test Fire safety, Moisture content and Thermal behavior of the panels (EN 10459). All of the tests that are mentioned in the standard were summarized in the European recommendations for reuse of steel products in single-story buildings (Coelho et al. 2020, 81) and the summary table from this study is provided below.

Evaluation criteria	Property
	Mechanical strength
Testing cross panel tensile strength 3 samples, a minimum (EN 14509, A1): Calculate characteristic result for tensile strength. Testing one sample for shear strength (EN 14509, A.3 or A.4)	
1. Tensile strength Actual value ≥ 0.9 x Declared value, and: 2. Shear strength Actual value ≥ 0.9 x Declared value	If YES, no further testing is required. All declared values for mechanical strength can be used.
	If NO, new declared values to be determined with a test programme according to EN 14509 for (i) tensile strength, (ii) compression strength, and (iii) shear strength. The wrinkling strength is reduced with the same amount that shear strength is reduced.
	Durability
Tensile strength Actual value ≥ 0.9 x Declared value	If YES, no further testing is required. Panels are fit for use.
	If NO: For Miwo panels: The 7 days testing (see EN 14509 clause B.3.4) is to be done. The reduction in tensile strength after ageing shall not exceed 15 % of the mean value of the tensile strength in ambient temperature For all other panel types: The procedure in EN 14509 Annex B.2 is followed so that the panels are tested 14 days in the temperature as described in B.2.4. The reduction in tensile strength after ageing shall not exceed 17% of the mean value of the tensile strength in ambient temperature
	Tolerances
Damage is evaluated by visual inspections	If no serious damages or faults are found, then the panel can be reused.
	If serious damages are found causing weakness in strength, insulation behaviour or tightness of joints, then those panels are rejected.
	Moisture content
Wetness of core material	If no notable wetness of core material found, the panels can be reused
	Thermal behaviour
For PU panels: 1. Closed cell ratio Actual value ≥ 0.9 x Value obtained by type testing and 2. Change in density < 10%	If YES, no further testing is required; original thermal conductivity value can be used.
	If NO, then new test for determining thermal conductivity is to be done following the rules in Section A.10 of EN 14509.
	Fire safety
Small flame tests, see clause C.1.2 of EN 14509	Tests to be done with core material including fire retardants. The classification is checked and if needed reclassified. The panels are fit for use where fulfilling the requirements in the project for reuse.

Table 3 Evaluation criteria for cladding (Coelho et al. 2020, 81)

In the researched case the inspection of the Paroc panels was not performed because after visual inspection there was not any doubt about the quality of the panels. They are also not exposed to severe weather conditions or fire threat.

3.5 Automated Excel sheet for dimensional tolerance inspection

This part will explain how inspection excel sheet can be used on the basis of the relocated warehouse in Lappeenranta. The excel sheet is automatic, however the important note is that this excel sheet was created for the inspection of the mentioned case and it needs close attention and attentive alternations if used in another project.

Colour	Meaning
(yellow)	**Cells should be edited accroding to original and measured values**
(blue)	**Cells should be edited accroding to standards**
(green)	**Succesful verification of tolerance**
(red)	**Tolerance verification failed, element can't be used in current state**
(white)	**Can't be changed, consists formula or information**

Table 4 Cell color explanation

Table 4 shows us the cell color legend, that can help us to use this table correctly and effectively.

First and foremost, when we inspect dimensions, we usually compare the original dimensions with the ones, that we took from disassembled element. Both original and new dimensions should be inserted in the table. These cells where we need to put original and measured value have the yellow color and should be changed first.

In some of the tests the tolerance rule is variable, depending on original dimensions or other factors. In this case we need to check the standard and choose correct tolerance. The needed extracts from the standards are provided next to the table and can be accessed easily. The color for cells, which require looking at the document is light-blue or cyan.

Then we also have the cells that should not be changed, as they consist of formulas and will function without user’s help. Such cells will be later used to determine whether characteristic is within the tolerance or not. They have white color.

The last cell type is green/red cell. They show us the result of all the input inserted in the table in a form of simple “Yes” (meaning that certain characteristic is within tolerance) or “No” (meaning that the tolerance is not met and this element cannot be reused).

Important note should be made about “Yes” and “No” cells. There is an exceptional case when we calculate CFRHS profile’s “External corner profile parameter”. The formula there could not be automated and have to be manually adjusted. In Appendix 4 the calculation example can be found along with explanation to the case above.

The necessary part of inspection is numbering the elements that will be inspected. This numbers will be later used in inspection report and will provide easier navigation for disassembling team.

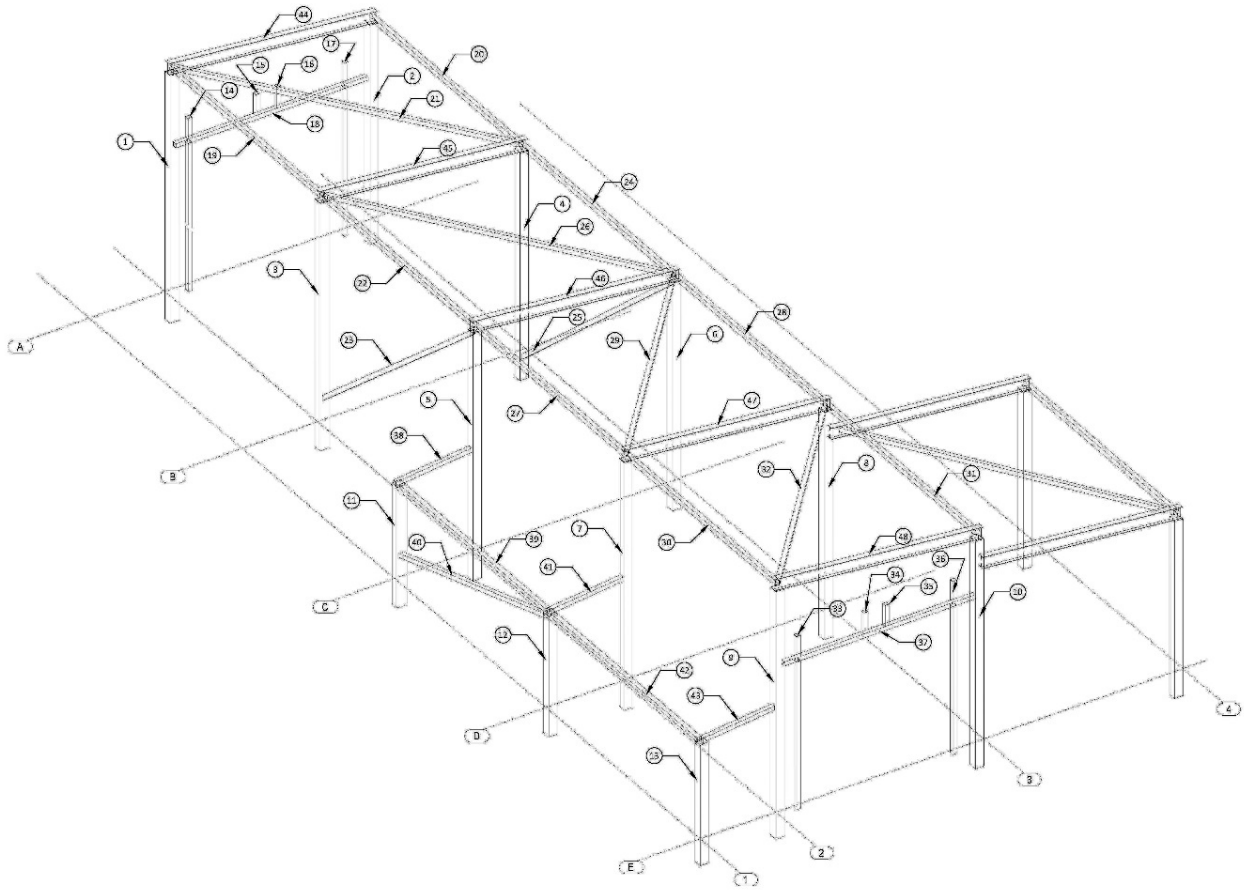

Figure 7 Numbered elements off the steel frame (source: Researched case)

The excel sheet has a separate tab for inspecting CFRHS elements, I-beams and PAROC elements. Here are some features and notes about each element:

- CFRHS elements. One table is used for one element. It has 5 rows that do not need any alternations and 4 rows, which should be altered according to standard (2 of 4 might need changing the formula)
- I-beams. One table is used for one dimensional characteristic. Two tables do not need alternations, 3 tables need simple alternations according to standard (no formula changes are needed)

- PAROC elements. Table checks only straightness of the panel; no alternations are needed. For more information on cladding inspection check Section 3.3.3.

Column number 1

Standards used: EN 10219-2 (Tolerances), check it for inspection instructions

Column number	Type of column	Characteristic	Initial (Manufacturer's) value	Actual value (take biggest deviation)	Square and rectangular hollow: Tolerance condition	Square and rectangular hollow: Tolerance	Within the tolarance?	Notes
1	CFRHS 100X100X5	Outside dimensions (B,H)	100	100	100 ≤ H,B ≤ 100	0.008	Yes	
		Thikness (T)	5	4.5	T ≤ 5 mm	0.1	Yes	Formula needs to be changed if tolerance condition changes
		Squareness of side	90	90	90° ± 1°	1	Yes	
		Length (L)	5900	5903	L<6 000mm	5	Yes	
		Concavity/convexity (x1, x2) b	Side of a square B, mm	The biggest of concavity (x1) or the convexity (x2)	$Deviation = \frac{x_1}{B} * 100\%$ Deviation should be less than 0.8%	0.8	No	
			100	1				
		External corner profile	Thikness, mm	C1 and C2, mm	T ≤ 6	1,6T to 2,4T		Formula needs to be changed if tolerance condition changes (Appendix 4)
			5	8			Yes	
				8			Yes	
		Twist (V)	Length, m	V, mm	2 mm plus 0,5 mm/m length	4.95	Yes	
			5.9	4				
		Straightness (e)	Length, mm	Maximum height of deviation, mm	$Deviation = \frac{e}{L} * 100\%$ Deviation should be less than 0.15% of total length	0.15	Yes	
			5900	8				
		Mass per unit length (M)	Initial mass per 1m, kg	Actual mass per 1m, kg	± 6 % on individual delivered lengths	0.06	Yes	
			30.12	31.8				

Type of column	Column number	All tolerances okay?
	1	No
	2	Yes
	3	Yes
	4	Yes
	5	Yes
	6	Yes
	7	Yes
	8	Yes
	9	Yes
	10	Yes
	11	Yes
	12	Yes
	13	Yes
	14	Yes
	15	Yes
	16	Yes

Table 5 Overlook at Excel sheet for CFRHS elements

The right end of Table 5, shows us the summary of inspection for each element giving us a visual representation of element's reusability. If any dimension is outside of the tolerance, we will get a "No" result next to the element number, meaning that this element cannot be reused.

This tool makes inspection of the dimensional tolerance easier and helps to provide an easy-to-read result. It is not a complete tool, but a foundation on which any dimensional inspection excel sheet can be made through correct information input and conscious editing of some parts of the table.

This excel sheet can be found in the attachments to the thesis.

4 Case study: Environmental impact of steel envelope warehouse relocation

4.1 Life Cycle Assessment

Any element of the building has to go through many stages before it is installed on site, but even after that there are even more stages to come in its lifecycle. All of stages that element has to come through have negative impact on the environment.

A Life Cycle Assessment (LCA) system was created to understand how each stage affects the environment. One of the goals of LCA is to make an estimation of carbon dioxide (CO_2) emissions produced during building part's lifecycle. (Simonen et al. 2019, 9)

Figure 8 shows the stages that every material goes through during its life.

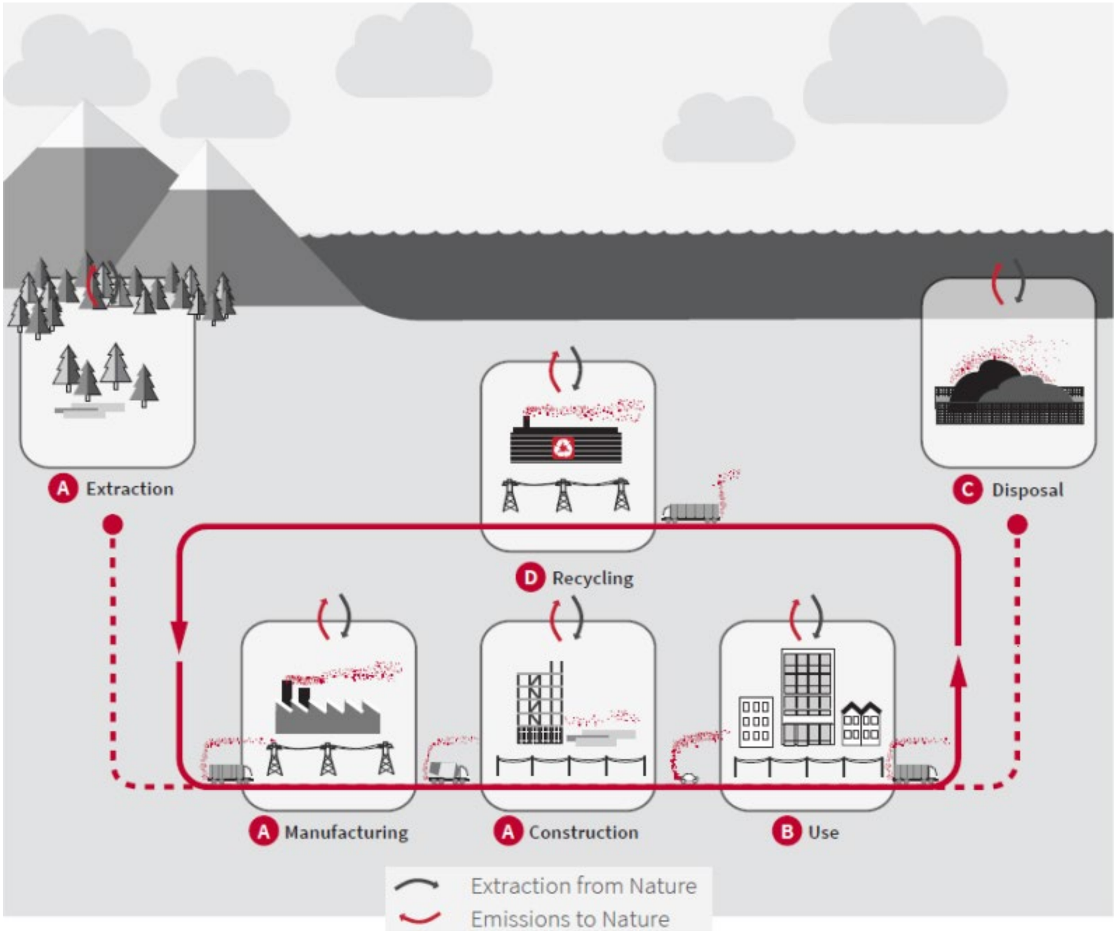

Figure 8 Lifecycle stages of construction material (Simonen et al. 2019, 8)

There are 4 main stages of Building's lifecycle. Each stage has several modules which represent the processes during the creation of a building part (I-beam, CFRHS profile, etc.).

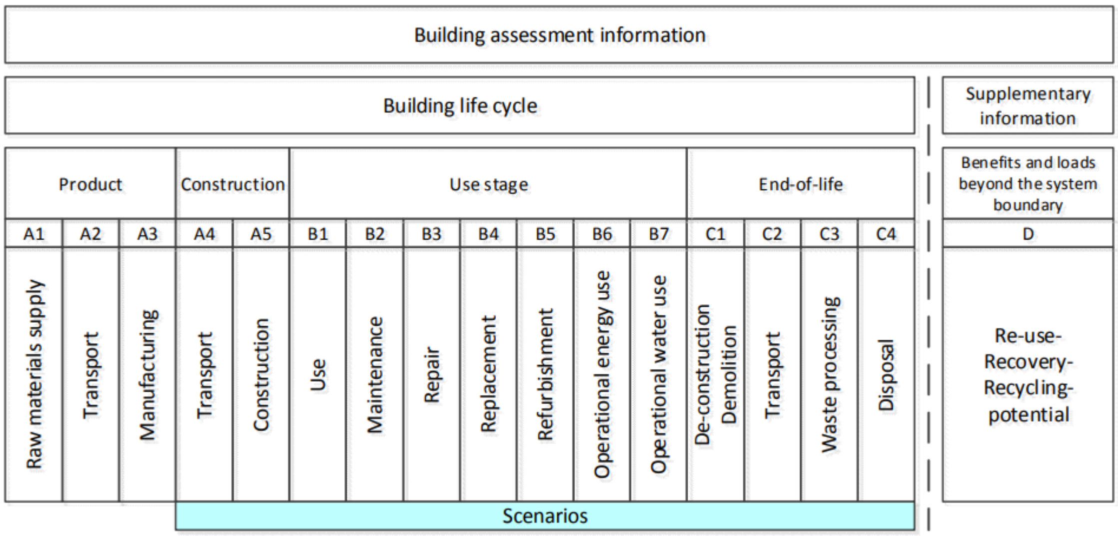

Table 6 Lifecycle stages of the building material (BRE Global 2018, 13)

According to BRE Global (2018, 14), here are the stages of the building's lifecycle:

1. Product stage (A1-A3) is divided to 3 modules:
    a. Raw material supply, A1. Energy spent on extracting building materials (e.g., mining steel, cutting trees).
    b. Transport, A2. Energy used to transport extracted materials to the manufacturer.
    c. Manufacturing, A3. Energy used to create end products that will be used in the building from raw materials.
2. Construction stage (A4-A5) is divided to 2 modules:
    a. Transport, A4. Energy used to transport elements to the site.
    b. Construction, A5. Energy used to mount elements in the correct place according to design.
3. Use stage (B1-B7) consists of 7 modules:
    a. Use, B1. Emissions produced by elements during their lifecycle (release of substances from the building façade)
    b. Maintenance, B2. Energy used to perform the regular maintenance of the structure (e.g., reapplying the fireproof paint on a structural element)

c. Repair, B3. Energy used on fixing the element of the structure that no longer can serve its function to the needed extent (e.g., mantling of concrete column after its section has decreased)

d. Replacement, B4. Energy used to replace elements of the structure with a shorter lifespan than the building (e.g., changing the windows with 30-year lifespan in the 60-year lifespan building)

e. Refurbishment, B5. Includes all of the energy used for a scheduled significant program that can consist of maintenance, repair and replacement of the existing elements (B2-B4) as well as adding of new elements to renew or repurpose the structure (A1-A5).

f. Operational energy use, B6. Energy used to provide electricity, heating and other energy needs of the structure.

g. Operational water use, B7. Energy used to provide water resources used by the building according to its purpose.

4. End-of-life stage (C1-C4) consists of 4 modules:

    a. De-construction or demolition, C1. Energy used to disassemble or demolish the building at the end of its lifecycle.

    b. Transport, C2. Energy used to transport the demolished parts to the site where element will be reused or recycling/disposal site.

    c. Waste processing, C3. Energy used to handle and sort the elements at the waste collection facility.

    d. Disposal, C4. Energy consumed by disposal facility to handle elements that were sent to the landfill at the end of their lifecycle.

5. Benefits and loads beyond system boundary, D. The only stage where we calculate the environmental benefits received from the end-of-life stage. Here we find out how much energy and therefore CO_2 emissions were saved due to recycling and reuse. (BRE Global 2018, 14.)

All of those modules have different impacts depending on the materials used, distances of transportation and other factors. The main European Standard that describes the calculation of the environmental impacts is EN 15978. There are also online tools available to make Life Cycle Assessment of the structure easier and give it a better look.

The main outcome of LCA used to consider the numerical environmental impact of the structure is Global Warming Potential (Simonen et al. 2019, 9). This is the parameter that is calculated for the case of Lappeenranta's Warehouse in this research.

4.2 Global Warming Potential of relocated warehouse in Lappeenranta region

In this research it was decided to calculate the GWP for two situations:

- new Warehouse created from raw materials
- relocated Warehouse (researched case)

The amount of energy saved as a result of relocating the steel envelope will be calculated and some conclusions made in this section.

The unit of measurement for GWP is kgCO_{2eq}/kg. It shows how many kilograms of carbon dioxide equivalent were emitted for 1 kg of produced building material. We use equivalent kilograms of CO_2 because carbon dioxide is not the only gas emitted in the lifecycle of building element. The CO_{2eq} includes all of the harmful gasses as well as carbon dioxide itself combined together. All of the gases are converted to the equivalent of CO2 (i.e., 1kg of methane CH_4 emission is the same as 25kg of CO_2, so 1 kg CH_4 = 25 kg CO_{2eq}). (Matthew Brander, 2)

The first thing that should be done prior to calculating GWP of the structure is inventory of the materials used. On Figure 9 the elements identified during inventory are used to calculate the total mass of the building.

1. Information about structure

IPE-270 : 5 elements

$m_{IPE} := 36.1 \ \frac{kg}{m}$ $\quad L_{IPE} := 4.95 \ m$ $\quad n_{IPE} := 5$

CFRHS 100x100x5 : 30 elements

$m_{RHS1} := 14.4 \ \frac{kg}{m}$ $\quad L_{RHS1.tot} := 138.5 \ m$

CFRHS 200x200x5 : 13 elements

$m_{RHS2} := 30.1 \ \frac{kg}{m}$ $\quad L_{RHS2} := \frac{5.9 \ m + 5.5 \ m}{2} = 5.7 \ m$ $\quad n_{RHS2} := 10$

$L_{RHS2'} := 2.9 \ m$ $\quad n_{RHS2'} := 3$

PAROC panels

$A_P := 260 \ m^2$

2. Total mass

$M_{IPE} := n_{IPE} \cdot m_{IPE} \cdot L_{IPE} = 893.5 \ kg$

$M_{RHS1} := m_{RHS1} \cdot L_{RHS1.tot} = 1994.4 \ kg$

$M_{RHS2} := m_{RHS2} \cdot \left(n_{RHS2} \cdot L_{RHS2} + n_{RHS2'} \cdot L_{RHS2'}\right) = 1977.6 \ kg$

$M_{tot} := M_{IPE} + M_{RHS1} + M_{RHS2} = 4865.4 \ kg$ - Mass of steelwork

$m_P := A_P \cdot 26.4 \ \frac{kg}{m^2} = 6864.0 \ kg$ - Mass of PAROC panels

Figure 9 Total mass of Warehouse’s envelope

When mass is defined, the unit impacts for different stages can be looked up in the standard. For this research the Methodology for LCA of buildings (Table 7) and Environmental Product Declaration for PAROC (Table 8) were used to define unit impacts from materials used in the building’s envelope.

		Blocks	Steel	Insulation	Cladding
Quantity, net	Q_M (kg)	10	5	2	3
GWP (kg CO_2 eq.) unit data for the respective information modules	A1	8	12	11	9
	A2	2	4	3	1
	A3	16	18	17	15
	A4	2	2	2	2
	A5	3	3	3	3
	B1	0	0	0	0
	B2	0	0	0	2
	B3	0	0	0	0
	B4	0	0	0	32
	B5	0	0	0	0
	B6	0	0	0	0
	B7	0	0	0	0
	C1	1	1	1	1
	C2	2	2	2	2
	C3	5	7	6	4
	C4	13	15	14	12

Table 7 Unit impacts for building materials based on lifecycle stages (Global 2018, 27)

Environmental impact										
Parameter	**Unit**	**A1-A3**	**A4**	**A5**	**B2**	**C1**	**C2**	**C3**	**C4**	**D**
GWP*	kg CO_2-eqv	3.72E+01	1.12E+00	1.88E+00	1.22E-01	8.81E-03	1.04E-01	5.58E-01	2.69E-01	-1.11E+01
ODP	eqv	9.75E-07	1.95E-16	1.70E-14	3.16E-08	1.50E-17	2.78E-17	9.34E-08	1.47E-15	-5.55E-14
POCP	kg C_2H_4-eqv	1.22E-01	2.72E-03	2.72E-03	3.72E-03	1.82E-05	2.36E-04	4.13E-03	1.61E-03	-2.43E-02
AP	kg SO_2-eqv	2.02E-02	6.47E-04	2.71E-04	1.89E-03	4.33E-06	5.65E-05	1.02E-03	1.82E-04	-2.36E-03
EP	kg PO_4^{3-}-eqv	1.26E-02	-8.49E-04	4.37E-04	5.35E-04	-6.01E-06	-8.15E-05	4.21E-04	1.23E-04	-4.04E-03
ADPM	kg Sb-eqv	1.34E-04	8.65E-08	6.95E-06	1.38E-05	1.52E-09	9.39E-09	9.25E-07	2.70E-08	-9.77E-07
ADPE	MJ	4.06E+02	1.51E+01	1.24E+01	1.09E+01	1.11E-01	1.39E+00	7.69E+00	3.65E+00	-9.35E+01

GWP Global warming potential; ODP Depletion potential of the stratospheric ozone layer; POCP Formation potential of tropospheric photochemical oxidants; AP Acidification potential of land and water; EP Eutrophication potential; ADPM Abiotic depletion potential for non fossil resources; ADPE Abiotic depletion potential for fossil resources. *The mandatory indicator GWP-IOBC from the PCR 010 version 3.0 Building Boards (04 2019) is likely equivalent to GWP. Trafikverket and Boverket, in Sweden, refer to this indicatior as GWP-GHG.

Table 8 Unit impacts for PAROC materials based on lifecycle stages (The Norwegian EPD Foundation 2021, 6)

When we look at the warehouse erected from new steel or raw material (RM in calculations) we can calculate all stages from A1 to D according to the standard:

$$E_{RM.tot} := m_{steel} \cdot \left(E_{RM.A1} + E_{RM.A23} + E_{RM.A4} + E_{RM.B} + E_{RM.C1} + E_{RM.C2} + E_{RM.C3} + E_{RM.C4} + E_{RM.D} \right)$$

In case of relocating the old frame, we take the Product stage (A1-A3) out of equation. Instead of Product stage we have demolition and transportation to the site (C1-A4):

$$E_{RE.tot} := m_{steel} \cdot \left(E_{RE.C1} + E_{RE.A4} + E_{RE.A} + E_{RM.B} + E_{RE.C1} + E_{RE.C2} + E_{RE.C3} + E_{RE.C4} + E_{RM.D} \right)$$

Due to the fact that we only need the difference between environmental impacts – all the stages shared between 2 cases do not need to be included in the final equation. Then, the final equation will have the following impacts:

- New steel frame: Stages A1 (Raw material supply), A2 (Transport to the manufacturing facility) and A3 (Steel manufacturing)
- Relocated steel frame: Stages C1 (Deconstruction)

In this case we do not consider the impact from transportation to the site, because there are some steel manufacturing facilities in Lappeenranta and the distance of relocation and factory-to-site transportation will be approximately the same. Therefore, the total difference is achieved through the equation:

$$E_{RM} := m_{steel} \cdot \left(E_{RM.A1} + E_{RM.A23} \right) = 33320.0\ kg_{CO2}$$

$$E_{RE} := m_{steel} \cdot E_{RE.C1} = 980.0\ kg_{CO2}$$

$$E_{S.benefit} := E_{RM} - E_{RE} = 32.3\ ton_{CO2}$$

Figure 17 The environmental impact achieved through frame relocation. Benefit from steel

The Paroc panels go through the similar cycle and the the final equation will have the following impacts:

- New steel frame: Stages A1 (Raw material supply), A2 (Transport to the manufacturing facility), A3 (Steel manufacturing) and A4 (Transportation from manufacturing facility to the site)
- Relocated steel frame: Stages C1 (Deconstruction) and A4 (Transport from an old site to the new site)

It was decided to include the impact from transportation to the site here, because the distance of relocation was 8 km and the closest Paroc factory to Lappeenranta is located in Helsinki which is approximately 230 km away from the site.

The impact for both cases (NP – new panel, RP – reused panel) is calculated below:

$$E_{NP} := A_P \cdot \left(E_{NP.A13} + E_{NP.A4}\right) = 9963.2\ kg_{CO2}$$

$$E_{RP} := A_P \cdot \left(E_{RP.C1} + E_{RP.A4}\right) = 12.5\ kg_{CO2}$$

$$E_{P.benefit} := E_{NP} - E_{RP} = 10.0\ ton_{CO2}$$

Figure 18 The environmental impact achieved through envelope relocation. Benefit from PAROC panels

After obtaining the GWP benefit from all of the relocated parts of the envelope – the total deduction of the carbon waste can be calculated:

$$E_{tot} := E_{S.benefit} + E_{P.benefit} = 42.3\ ton_{CO2}$$

Figure 19 Total environmental benefit achieved through relocation

The results are presented on the Figure 20. The relocated warehouse emits approximately 43 times less carbon dioxide into the atmosphere than the warehouse manufactured from new steel. The only noticeable impact from the relocated frame was due to disassembling, the distance of transportation of the relocated frame was only 8 km and did not have significant environmental impact.

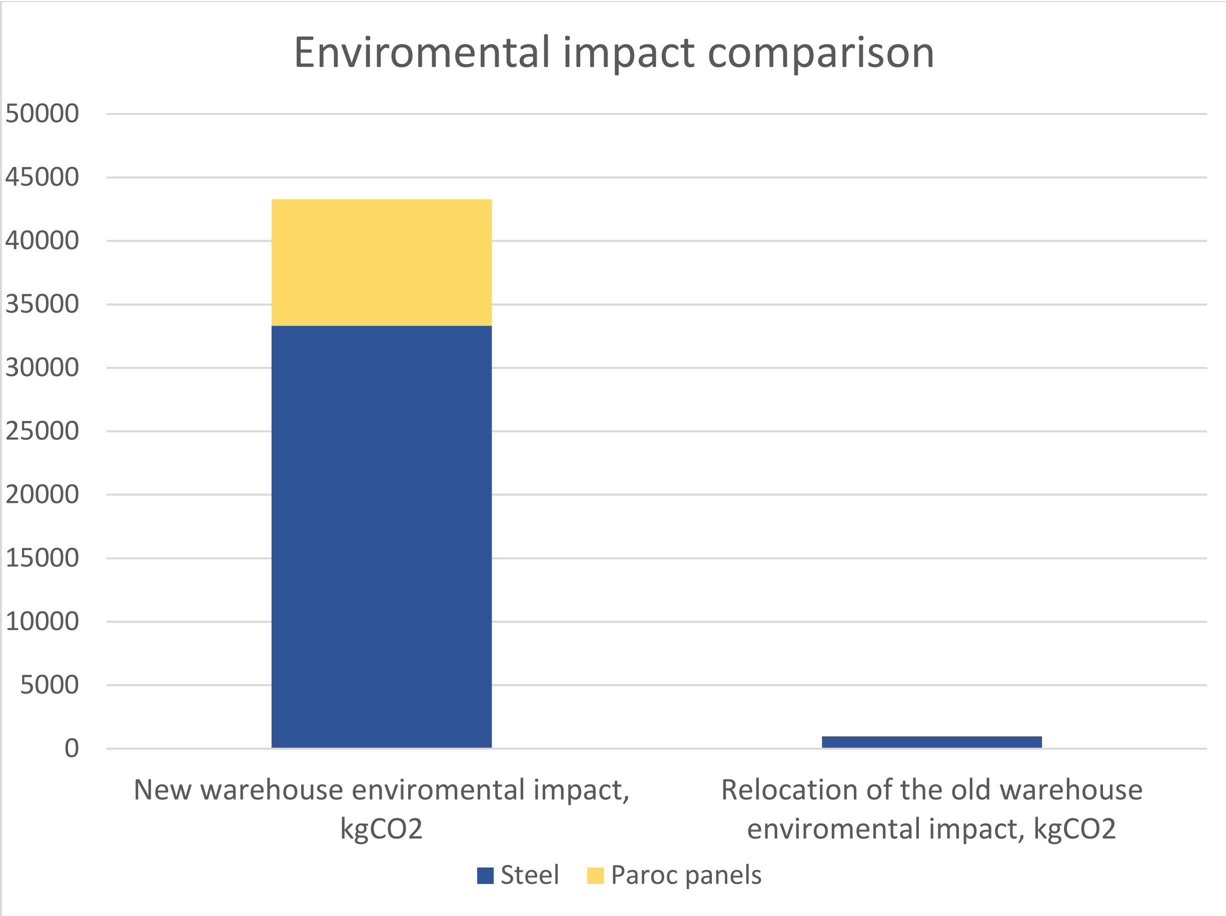

Figure 20 The representation of global warming potential for newly manufactured and relocated one-story warehouse

According to Greenhouse Gas Equivalencies Calculator the amount of saved energy is equivalent for providing electricity for 1 year for 8.2 homes or energy enough to charge 5.1 million smartphones. This relocated warehouse is a relatively small 5 tonne building, therefore these results can be considered quite notable.

There are some examples of much bigger steel frame relocations as much as 3720 tonne BRE test facility in Cardington, UK (Coelho et al. 2020, 20). It means that buildings of any scales can be relocated and the potential environmental impact from the reuse of steel structures should be always thought of.

The full calculations can be found in Appendix 4.

5 Summary

In this thesis the process of steel frame dimensional inspection was described according to the European Standards. The main focus of this research was inspecting the elements used in the studied case. As the result the automated excel sheet was developed to speed up the inspection process and make the outcome easier to read. The excel sheet is mainly designed for inspecting CFRHS and I-beams and it can be also used as a starting point for inspecting CFCHS, hot rolled sections and other steel elements.

The recommendations for inspection of steel frame given in this thesis are not mandatory and can be used if there is a specific need to check some of the dimensional characteristics. The inspection report was not created for the TTV-kiinteistöt Oy as there was no need to perform dimensional tolerance inspection according to visual inspection and field survey.

In the environmental part of the research the Lifecycle stages of the building elements were described to understand what processes contribute to pollution. The calculations were performed to see the effect that can be achieved through the reuse of steel.

According to the calculation results the benefit achieved through the relocation of the steel frame can be very significant. It is due to the high energy consumption during steel manufacturing.

It should be mentioned that manufacturing companies already reuse and recycle the steel to a great extent and every new steel element has some recycled, melted down steel in its composition. The calculations in this thesis compare the impact from steel manufactured from purely new raw material and steel entirely reused through relocation.

Nevertheless, the results obtained from calculations show us the importance of reuse and recycling during the manufacturing stage. As this stage is the most polluting, it is always important to think how it can be avoided or minimized. In the future, this question should be raised throughout all parties involved in the contract. The client and architect can find a way to reduce the global warming potential of the building through reuse and environmentally friendly materials. The designing team could give a considerable thought about the future of the building, how to make it easy to reuse and relocate. This way the maximum potential of steel's sustainability can be achieved.

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Appendix 1. Weld splice inspection results (translated from Finnish).

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kiwa

INSPECTION REPORT / INSPECTION REPORT
Magnetic particle examination

FINAS Finnish Accreditation Service
T011 (EN ISO/IEC 17025)
I005 (EN ISO/IEC 17020)
(Tyyppi A / Type A)

Work no	Chapter No. / Document no.	Rev. Well.	Order No./ Sequence no.	Page / Sheet
WO-00945620	71397833339 0			1 of 2
Attachments: -	Attachments pcs. / Attachments pcs.: -	Customer's document no.: -		
Inspection plan no.: -				

Office: 551 FI - 551 NDT Kotka+Kouvola+Lpr

Subscriber / Purchaser	Create Oy
Plant or place of inspection	Kreate, Lentokänttie 65 Lappeenranta
Inspection object Job: 22020	**Inspection of the joints of the lower ends of the steel columns.**
Welds (Result/Notes/Welder Stamp) / Welds (Result/Notes/ Welder Stamp)	**13 pillars.**
Drawing no.	7003
Rev. No.	-
Base material	CS
Nominal dimensions	200x200x5
Surface quality / Surface Condition	Used
Temperature	20 °C
Heat treated	No
Inspection procedure	ISO 17638:2016/NDT-MT-01
Rev. No.	-
Quality requirement	Findings are reported
Scope of examination	100%
Magnetization equipment used	Parker
Equipment no.	356
Equipment and type of light	General lighting
Equipment no.	-
Pre-cleaning of surface / Indication of method	Sandblasting
	☒ Colored ☐ Fluorescent / Fluorecent
Contrast media - Batch	Bycotest 104 210207
Magnetization method	☐ Permanent magnet / Permanent magnet ☒ Ies / Yoke ☐ Coil / Coil ☐ Sections / Prods ☐ Direct current / Direct current ☐ Central conductor
Magnet particle - Batch	Bycotest 103 200215
Type of current	☐ Permanent magnet / Permanent magnet ☒ Alternating current / AC ☐ Direct current / DC ☐ Pulse current / Pulse current
Prod or pole spacing	200
Power / Current	-A
Round no. / Well. of turns	-
Directions of magnetization	90° to each other
Demagnetization / Demagnetization	☐ yurttot / is carried out ☒ Not carried out / is not carried out
Past examination cleaning	Not completed

Observations and deviations from inspection manual
- Pillars P1-P12, no reportable scenes.
- Pillar P13, linear stage area, length approx. 8 mm.

Overview of the pillars.

The welds of the lower ends of the pillars are sandblasted.

Inspection results / Result of inspection

○ Fill the requirements / Fulfills requirements ○ Corrected, meets requirements / Repaired, fulfills requirements ○ Does not meet the requirements / Does not fulfill requirements ⊗ Findings are reported / Observations are reported

Name of Inspector	Signature	Place / Place	Date	Competence
Pasi Valkeapää	[signature]	Lappeenranta	08/08/2022	SFS-EN ISO 9712 7139 L2

Supervisor
-

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Work no	Chapter No. / Document no.	Rev. Well.	Order No./ Sequence no.	Page / Sheet
WO-00945620	71397833339	0		2 of 2

Attachments	Attachments pcs. / Attachments pcs.	Customer's tax no document no.
-	-	-

Inspection plan no.
-

Kontori - Office: 551 FI - 551 NDT Kotka+Kouvola+Lpr

Pillar P13

Displayed by Pillar P13.

Pillar P13 shown, length approx. 8 mm.

Name of Inspector	Signature	Place / Place	Date	Competence
Pasi Valkeapää	Pasi Valkeapää	Lappeenranta	08/08/2022	SFS-EN ISO 9712 7139 L2

Supervisor
-

Appendix 2. Extract from EN 10219-2. Cold formed welded structural hollow sections of non-alloy and fine grain steels. Tolerances on shape and dimensions.

Characteristic	**Circular hollow sections**	**Square and rectangular hollow sections**	
Outside dimensions (D, B and H)	± 1 % with a minimum of ± 0,5 mm and a maximum of ±1 0 mm	Side length mm	Tolerance
		H, B <100	± 1 % with a minimum of ± 0,5 mm
		100 ≤ H, B ≤ 200	± 0,8 %
		H,B > 200	± 0,6 %
Thickness (T)	For D ≤ 406,4 mm: T ≤ 5 mm ± 10 % T > 5 mm ± 0,5 mm For D > 406,4 mm: ± 10 % with a maximum of ± 2 mm	T ≤ 5 mm ± 10% T > 5 mm ± 0,5 mm	
Out-of-roundness (O)	2 % for hollow sections having a diameter to thickness ratio not exceeding 100 [a]	—	
Concavity/convexity (x_1, x_2) [b]	—	Max. 0,8 % with a minimum of 0,5 mm	
Squareness of side (θ)	—	90° ± 1°	
External corner profile (C_1, C_2 or R)	—	See Table 3	
Twist (V)	—	2 mm plus 0,5 mm/m length	
Straightness (e)	0,20 % of total length and 3 mm over any 1 m length	0,15 % of total length and 3 mm over any 1 m length	
Mass per unit length (M)	± 6 % on individual delivered lengths		

[a] Where the diameter to thickness ratio exceeds 100 the tolerance on out-of-roundness shall be agreed.

[b] The tolerance on convexity and concavity is independent of the tolerance on outside dimensions.

Table 1 Tolerances on shape and mass (EN 10219-2:2006, 6)

Dimensions in millimetres

Thickness T	External corner profile C_1, C_2 or R [a]
$T \leq 6$	1,6T to 2,4T
$6 < T \leq 10$	2,0T to 3,0T
$10 < T$	2,4T to 3,6T

[a] The sides need not be tangential to the corner arcs.

Table 2 Tolerances on external corner profiles (EN 10219-2:2006, 7)

Dimensions in millimetres

Type of length [a]	Range of length or length L	Tolerance
Random length	$4\,000 < L \leq 16\,000$ with a range of 2 000 per order item	10 % of sections supplied may be below the minimum for the ordered range but not shorter than 75 % of the minimum range length
Approximate length	$\geq 4\,000$	$^{+50}_{0}$ mm
Exact length [b]	<6 000	$^{+5}_{0}$ mm
	$6\,000 \leq L \leq 10\,000$	$^{+15}_{0}$ mm
	>10 000	$^{+5}_{0}$ mm +1 mm/m

[a] The manufacturer shall establish at the time of enquiry and order the type of length required and the length range or length.

[b] Common lengths available are 6 m and 12 m.

Table 3 Tolerances on manufacturer's delivered length (EN 10219-2:2006, 7)

Appendix 3. Extract from EN 10034. Structural steel I and H sections. Tolerances on shape and dimensions.

1 Scope

This European Standard specifies tolerances on shape dimensions and mass of structural steel I and H sections. These requirements do not apply to I and H sections rolled from stainless steel. These requirements do not apply to taper flange sections.

NOTE Until a European Standard for dimensions of I and H beams is published Euronorm 19 and Euronorm 53 or corresponding national standards may be used.

2 Normative references

This European Standard incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies.

EN 10079, *Definition of steel products.*

Euronorm 19:1957, *IPE beams, parallel flanged beams.*

Euronorm 53:1962, *Wide flange beams with parallel flanges.*

3 Definitions

For the purpose of this European Standard, the definitions in EN 10079 apply.

4 Rolling tolerances for structural steel I and H sections

4.1 Section height *(h)*

The deviation from nominal on section height measured at the centre line of web thickness shall be within the tolerance given in Table 1.

4.2 Flange width *(b)*

The deviation from nominal on flange width shall be within the tolerance given in Table 1.

4.3 Web thickness *(s)*

The deviation from nominal on web thickness measured at the mid-point of dimension h shall be within the tolerance given in Table 1.

4.4 Flange thickness *(t)*

The deviation from nominal on flange thickness measured at the quarter flange width point shall be within the tolerance given in Table 1.

4.5 Out-of-squareness $(k + k')$

The out-of-squareness of the section shall not exceed the maximum given in Table 2.

4.6 Web off-centre *(e)*

The mid-thickness of the web shall not deviate from the mid-width position on the flange by more than the distance *(e)* given in Table 2.

4.7 Straightness $(q_{xx}$ *or* $q_{yy})$

The straightness shall comply with the requirements given in Table 3.

5 Tolerance on mass

The deviation from the nominal mass of a batch or a piece shall not exceed ± 4.0 %.

The mass deviation is the difference between the actual mass of the batch or piece and the calculated mass.

The calculated mass shall be determined using a density of 7,85 kg/dm^3.

6 Tolerance on length

The sections shall be cut to ordered lengths to tolerances of:

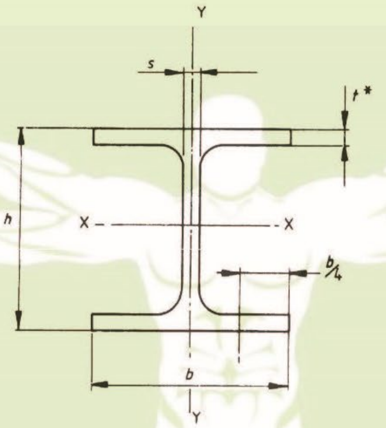
a) ± 50 mm; or

b) + 100 mm where minimum lengths are requested.

L represents the longest useable length of the section assuming that the ends of the section have ben cut square (see Figure 1).

Figure 1 Additional information about tolerance for I- and H-beams (EN 10034:1993, 3)

Table 1 — Dimensional tolerances for structural steel I and H sections

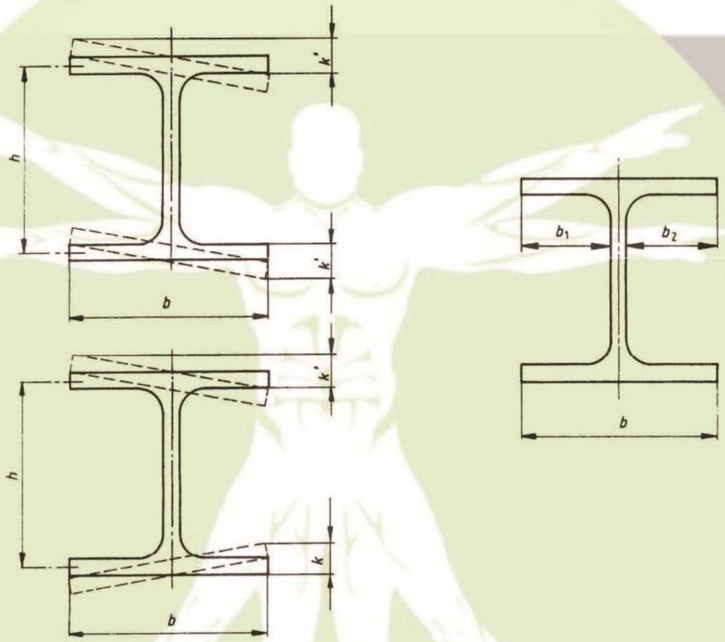


* t is measured at $b/4$
(see clause 4.4.)

Section height h		Flange width b		Web thickness s		Flange thickness t	
height mm	tolerance mm	width mm	tolerance mm	thickness mm	tolerance mm	thickness mm	tolerance mm
$h \le 180$	+ 3,0 − 2,0	$b \le 110$	+ 4,0 − 1,0	$s < 7$	± 0,7	$t < 6{,}5$	+ 1,5 − 0,5
$180 < h \le 400$	+ 4,0 − 2,0	$110 < b \le 210$	+ 4,0 − 2,0	$7 \le s < 10$	± 1,0	$6{,}5 \le t < 10$	+ 2,0 − 1,0
$400 < h \le 700$	+ 5,0 − 3,0	$210 < b \le 325$	+ 4,0 − 4,0	$10 \le s < 20$	± 1,5	$10 \le t < 20$	+ 2,5 − 1,5
$h > 700$	+ 5,0 − 5,0	$b > 325$	+ 6,0 − 5,0	$20 \le s < 40$	± 2,0	$20 \le t < 30$	+ 2,5 − 2,0
				$40 \le s < 60$	± 2,5	$30 \le t < 40$	+ 2,5 − 2,5
				$s \ge 60$	± 3,0	$40 \le t < 60$	+ 3,0 − 3,0
						$t \ge 60$	+ 4,0 − 4,0

Figure 2 Dimensional tolerance for I- and H-beams (EN 10034:1993, 4)

Table 2 — Tolerances on out-of-square and web off-centre of structural steel I and H sections

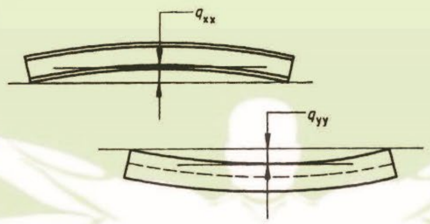


Out-of-square $k + k'$		Web off-centre e where $e = \frac{b_1 - b_2}{2}$	
flange width b mm	**tolerance** mm	**flange width b** mm	**tolerance** mm
$b \leq 110$	1,5	Where $t < 40$	
$b > 110$	2 % of b	$b \leq 110$	2,5
	(max 6,5 mm)	$110 < b \leq 325$	3,5
		$b > 325$	5,0
		Where $t \geq 40$	
		$110 < b \leq 325$	5,0
		$b > 325$	8,0

Figure 3 Out-of-square and web off-center tolerance for I- and H-beams (EN 10034:1993, 5)

EN 10034:1993

Table 3 — Tolerances on straightness of structural steel I and H sections



Section height h mm	Tolerance on straightness q_{xx} and q_{yy} on length L %
$80 < h < 180$	0,30 L
$180 < h \leq 360$	0,15 L
$h > 360$	0,1 L

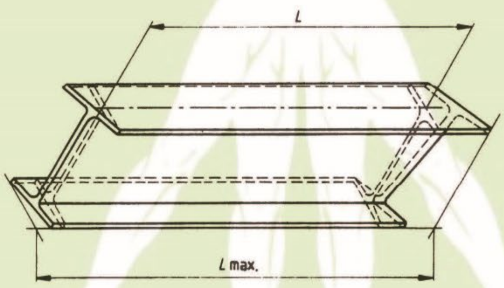


Figure 1 — Measurement of length L on I and H steel sections

Figure 4 Straightness tolerance for I- and H-beams (EN 10034:1993, 6)

Appendix 4. Example of working with table. Manual formula correction.

In this example we will take a look at external corner profile characteristic of Cold Formed Rectangular Hollow Section (CFRHS profile). The table already has values to see the order of numbers, it helps to make table easier to work with.

Column number 1			Standards used: EN 10219-2 (Tolerances), check it for inspection instructions				
Column number	Type of column	Characteristic	Initial (Manufacturer's) value	Actual value (take biggest deviation)	Square and rectangular hollow Tolerance condition	Tolerance	Within the tolarance?
		Outside dimensions (B,H)	200	200	100 ≤ H,B ≤ 200	0.008	Yes
		Thikness (T)	5	4.5	T ≤ 5 mm	0.1	Yes
		Squareness of side	90	90	90° ± 1°	1	Yes
		Length (L)	5900	5903	L<6 000mm	5	Yes
		Concavity/convexity (x1, x2) b	Side of a square B, mm	The biggest of concavity (x1) or the convexity (x2)	$Deviation = \frac{x_1}{B} * 100\%$ Deviation should be less than 0.8%	0.8	Yes
			200	1			
1	CFRHS 200X200X5	External corner profile	Thikness, mm	C1 and C2, mm	T ≤ 6	1,6T to 2,4T	Yes
			5	8			
				8			Yes

Original thickness of profile was 7 mm and we measured C1 and C2 dimensions which are 15 mm in our case. Firstly, we need to put the original and measured values into the table. Then, we should take a look at the standard, as blue cells imply this.

Dimensions in millimetres

Thickness T	External corner profile C_1, C_2 or R [a]
$T \leq 6$	$1{,}6T$ to $2{,}4T$
$6 < T \leq 10$	$2{,}0T$ to $3{,}0T$
$10 < T$	$2{,}4T$ to $3{,}6T$
[a] The sides need not be tangential to the corner arcs.	

Table 1 Tolerances on external corner profiles (EN 10219-2:2006, 7)

According to the Figure 11 we can find our thickness range and its tolerance. Here is how the table will look like after our alternations.

1	CFRHS 200X200X5	External corner profile	Thikness, mm	C1 and C2, mm	6 < T ≤ 10	2T to 3T	Yes
			7	15			
				15			Yes

The last thing that we need to do is we need to change the formula.

1.6 T to 2.4 T range changed to 2T to 3T, therefore we need to change the following values in the last “Yes” / “No” (Within the tolerance?) column:

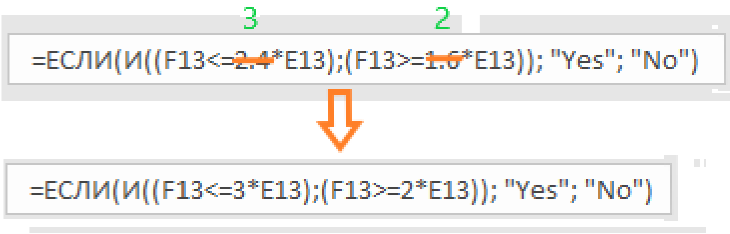


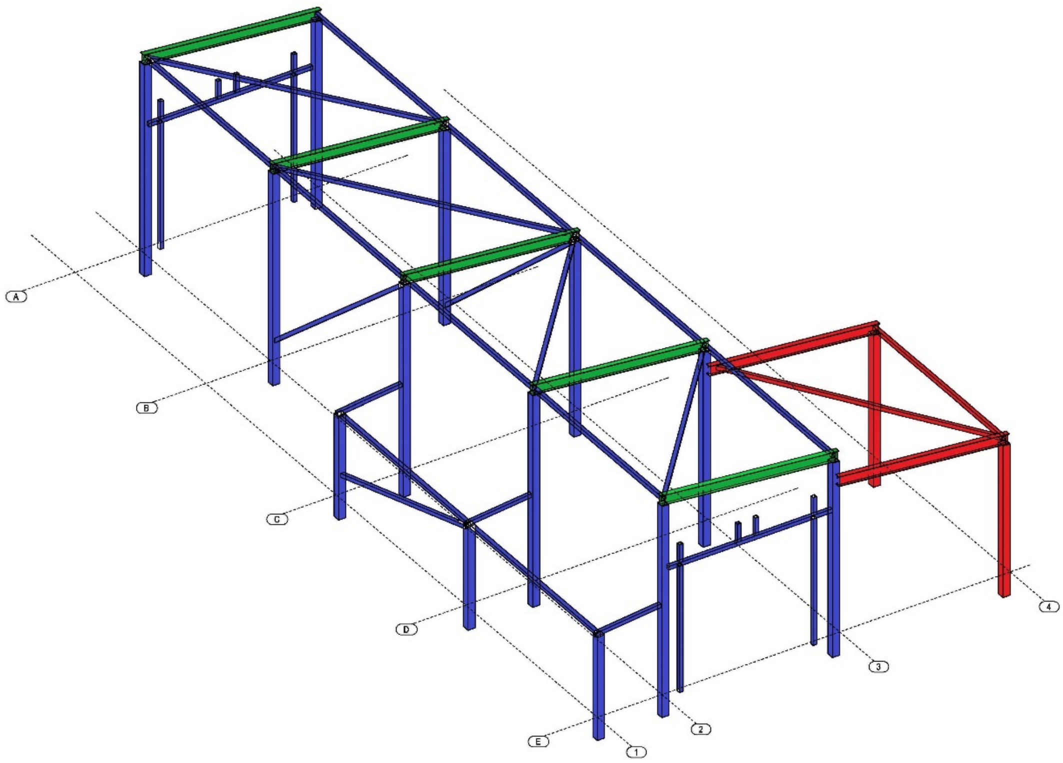
Figure 1 Fixing of the formula according to the standard. Translation of Excel formula to English: “ЕСЛИ“ = “IF“ ; “И“ = “AND“

The results are the right columns (in this case both C1 and C2 should be within tolerance) showing us “Yes”, which means that this characteristic is within the tolerance.

Appendix 4. Calculation of global warming potential.

One-story warehouse steel envelope. Global warming potential (EN15804).

1. Drawing



2. Steel environmental impact

$m_{steel} := 4900\ kg_{steel}$

Product stage (A) — RM - steel from raw material; RE - reused steel

$E_{RM.A1} := 2.4\ \frac{kg_{CO2}}{kg_{steel}}$ Carbon impact from raw material supply (A1)

$E_{RM.A23} := 4.4\ \frac{kg_{CO2}}{kg_{steel}}$ Carbon impact from transportation and manufacturing (A2+A3)

$E_{RE.A} := 0\ \frac{kg_{CO2}}{kg_{steel}}$ Carbon impact from reused steel (A1-A3)

$E_{RM.A4} := 0.4\ \frac{kg_{CO2}}{kg_{steel}}$ $E_{RE.A4} := E_{RM.A4}$ Carbon impact from transportation to the site (A4)

$E_{A5} := 0.6\ \frac{kg_{CO2}}{kg_{steel}}$ Carbon impact from construction (A5)

Use stage (B)

$E_B := 0 \ \frac{kg_{CO2}}{kg_{steel}}$ Carbon impact from use stage for steel (B1-B7)

End-of-life stage (C)

$E_{RE.C1} := 0.2 \ \frac{kg_{CO2}}{kg_{steel}}$ $E_{RM.C1} := E_{RE.C1}$ Carbon impact from deconstruction (C1)

$E_{RE.C2} := 0.4 \ \frac{kg_{CO2}}{kg_{steel}}$ $E_{RM.C2} := E_{RE.C2}$ Carbon impact from transport (C2)

$E_{RE.C3} := 1.4 \ \frac{kg_{CO2}}{kg_{steel}}$ $E_{RM.C3} := E_{RE.C3}$ Carbon impact from waste processing (C3)

$E_{RE.C4} := 1.4 \ \frac{kg_{CO2}}{kg_{steel}}$ $E_{RM.C4} := E_{RE.C4}$ Carbon impact from disposal (C4)

3. Steel global warming potential benefit (GWP)

$$E_{RM.tot} := m_{steel} \cdot \left(E_{RM.A1} + E_{RM.A23} + E_{RM.A4} + E_{RM.B} + E_{RM.C1} + E_{RM.C2} + E_{RM.C3} + E_{RM.C4} + E_{RM.D}\right)$$

$$E_{RE.tot} := m_{steel} \cdot \left(E_{RE.C1} + E_{RE.A4} + E_{RE.A} + E_{RM.B} + E_{RE.C1} + E_{RE.C2} + E_{RE.C3} + E_{RE.C4} + E_{RM.D}\right)$$

$$E_{RM} := m_{steel} \cdot \left(E_{RM.A1} + E_{RM.A23}\right) = 33320.0 \ kg_{CO2}$$

$$E_{RE} := m_{steel} \cdot E_{RE.C1} = 980.0 \ kg_{CO2}$$

$$E_{S.benefit} := E_{RM} - E_{RE} = 32.3 \ ton_{CO2}$$

4. PAROC panel environmental impact

$A_P := 260 \ m^2$ $m_P := A_P \cdot 26.4 \ \frac{kg}{m^2} = 6864.0 \ kg$

Product stage (A) NP - new panel; RP - reused panel

$E_{NP.A13} := 37.2 \ \frac{kg_{CO2}}{m^2}$ Carbon impact from raw material supply, transportation and manufacturing (A1-A3)

$E_{RP.A13} := 0 \ \frac{kg_{CO2}}{m^2}$ Carbon impact from reused panel (A1-A3)

$E_{NP.A4} := 1.12 \ \frac{kg_{CO2}}{m^2}$ Carbon impact from transportation to the site for new panels (A4) (230 km)

$E_{RP.A4} := 0.04 \ \frac{kg_{CO2}}{m^2}$ Carbon impact from transportation to the site for old panels (A4) (8 km)

$E_{P.A5} := 1.88 \ \frac{kg_{CO2}}{m^2}$ Carbon impact from construction (A5)

End-of-life stage (C)

$E_{NP.C1} := 0.008 \ \frac{kg_{CO2}}{m^2}$ $E_{RP.C1} := E_{NP.C1}$ Carbon impact from deconstruction (C1)

$E_{NP.C2} := 0.104 \ \frac{kg_{CO2}}{m^2}$ $E_{RP.C2} := E_{NP.C2}$ Carbon impact from transport (C2)

$E_{NP.C3} := 0.558 \ \frac{kg_{CO2}}{m^2}$ $E_{RP.C3} := E_{NP.C3}$ Carbon impact from waste processing (C3)

$E_{NP.C4} := 0.269 \ \frac{kg_{CO2}}{m^2}$ $E_{RP.C4} := E_{NP.C4}$ Carbon impact from disposal (C4)

5. PAROC panel global warming potential benefit (GWP)

$$E_{NP} := A_P \cdot \left(E_{NP.A13} + E_{NP.A4}\right) = 9963.2 \ kg_{CO2}$$

$$E_{RP} := A_P \cdot \left(E_{RP.C1} + E_{RP.A4}\right) = 12.5 \ kg_{CO2}$$

$$E_{P.benefit} := E_{NP} - E_{RP} = 10.0 \ ton_{CO2}$$

5. Total global warming potential benefit (GWP)

$$E_{tot} := E_{S.benefit} + E_{P.benefit} = 42.3 \ ton_{CO2}$$