ASSESSMENT METHOD FOR REUSE POTENTIAL OF RECLAIMED STEEL ELEMENTS

Gabi Janse
Faculty of Architecture & the Built Environment, Delft University of Technology
Julianalaan 134, 2628BL Delft

ABSTRACT

Steel production stands out as one of the most energy-intensive industries globally. Shifting towards a more circular system could be achieved by component reuse. Unfortunately, there is lack of information on how to assess the reuse potential of diverse steel components. This paper focuses on developing an assessment method for the reuse potential of thirteen common steel product groups, in which components found in three case-study buildings on the TU Delft Campus are categorized. The research process includes; compiling an inventory of components, identifying factors impacting the reuse process and conducting a value assessment. Not only can establishing this method contribute to achieving circular objectives outlined in the TU Delft's Sustainable Vision, it can also serve as an exemplary proposal to developers to apply this method and implement reclaimed steel components into their projects.

KEYWORDS: *Steel, Component Reuse, Reuse Potential, Value Assessment, Circularity*

INTRODUCTION

The building sector accounts for 40% of national CO_2 emissions. Among the contributors to this environmental impact, steel production stands out as one of the most energy-intensive and CO_2-emitting industries globally. For example, Tata Steel IJmuiden, a major steel producer, is the largest polluter of the Netherlands (Frisse Wind Nu!, 2023). Shifting towards a more circular system for steel elements, could be achieved through urban mining. *Urban mining* is the activity of recovering materials from anthropogenic stocks, where buildings are one of the most important stocks, since these are responsible for the highest rates of natural resource extraction (Bender & Bilotta, 2019). *Local harvesting* is about mining materials from nearby or regional sources, to reduce transportation emissions and supporting the local economy (Agudelo-Vera et al, 2012). *Component reuse* is the practice of salvaging and reusing specific building elements from existing structures in new/other constructions, aiming to reduce waste and promote sustainability. The term 'reuse' can be divided into *conventional reuse*; reusing items for their original purpose, or *creative reuse/repurposing*; reusing to fulfil a different function (Alaka et al, 2012).

Delft University of Technology aims to achieve carbon neutrality by 2030, aligning with its Sustainable Vision 2022. However, outdated construction methods have left several TU Delft campus buildings below current sustainability standards; The Faculty of Electrical Engineering, Mathematics and Computer Science (EWI), Yellow Chemistry (GS) and Applied Physics (TN) are the first on the list of comprehensive renovation or demolition (Blom & van den Dobbelsteen, 2019). EWI has one of the highest energy consumptions on campus and along with its fire-safety issues, its fate has been a topic of debate. GS faces sale due to its decay and whether to demolish or renovate it, rests with the new owner. TN ranks lowest in energy performance of all TU buildings (Appendix A, figure 4) (Blom & Van den Dobbelsteen, 2019). In the Sustainable Vision the goals for reuse and new construction are established. New buildings should consist of 10% of materials harvested from to be renovated or to be demolished campus buildings. Of the outdated campus projects, 80% of the materials that will become available should be reused in new (campus) buildings (Appendix A, figure 3) (Gameren & Van den

Dobbelsteen, 2022). This is relevant to the urban development of TU Delft Campus South, spanning 320.000 m^2, what in the near future will be filled with numerous new campus and office buildings (Posad Maxwan & TU Delft CRE, 2019). Since steel elements were widely used and applied in numerous ways during the period the outdated buildings were completed (approx. 1945-1970), it is advantageous to investigate whether these steel components are suitable for reuse.

A critical issue is the lack of comprehensive information on the availability and reuse potential of steel components. Existing studies predominantly examine primary structural steel, while last-century construction methods showcase more diverse steel applications (Birhane et al, 2023). Without a systematic approach to reuse, steel components, despite their potential, may likely end up as demolition waste. Thus, the objectives outlined in the Vision will not be realized, while contributing to larger-scale environmental challenges. Therefore, this paper will focus on developing an assessment method for the reuse potential of steel components that could be applied on the campus buildings and on other buildings with similar steel product groups, resulting in the following research question:

> How can reclaimed steel elements from TU Delft's outdated campus buildings be assessed for component reuse?

The following sub-questions will help address the main research question and will also serve as a guideline throughout this paper;

- Why reusing steel components?
- Which components will be investigated and why?
- Which factors influence the reusability potential of a steel component and how?
- How to convert the reuse potential of the components into a value assessment?

Method

The research involves analysing three campus buildings' steel components quantitatively and qualitatively to assess their potential for reuse or repurpose. The research process includes; compiling an inventory of components, identifying factors impacting the reuse process and conducting a value assessment. The case study buildings will be EWI, TN and GS, as these are currently under debate for demolition or renovation, driven by TU Delft's sustainability standards. Initial data collection involves a thorough examination of plans, sections, details, and on-site observations, followed by calculations to estimate the quantity of available steel components. Building on this quantitative foundation, a detailed qualitative analysis is conducted, identifying factors that influence the reuse potential for each component. The level of influence will be determined, by investigating how a factor affects a specific component. Finally, steel components of the case study can be assessed if they are suited for reuse. A decision chart is crafted as a tool to decide whether a component can be reused in its original role or if repurpose would be more suitable.

I. COMPONENTS

During the period from 1945 to the 1970s, various typical building components included steel. Some of these components have evolved or are used differently today due to advancements in construction practices, changes in sustainability considerations, and a better understanding of indoor climate quality. Examples are single-glazed steel windows, steel curtain wall systems, steel roof decking without insulation, steel HVAC ductwork without insulation, steel construction with limited fire resistance and steel framing without thermal breaks (Birhane et al, 2023). These components can be recognized in the case study buildings and contributed to the inadequate environmental and/or safety performances of EWI, TN and GS. When selecting the case study buildings, the initial focus was not solely on the quantity of steel in a building. A diverse range of case study buildings introduces more variables influencing the potential for reuse. For instance, the monumental factor of (steel) components in GS is significantly higher than that in TN or EWI, thus an interesting building to include. Chapter 2 delves into the specific factors influencing the potential for component reuse.

In Appendix A figure 5, a list can be found with frequently recurring steel elements found in the case study buildings. Within the timeframe of the study, it is not possible to individually address all these components to determine their reuse potential. Therefore, it has been decided to categorize them into representative main categories. The report: Life-cycle assessment (LCA) for steel construction from the European Commission (2003) describes the findings from a life-cycle assessment study of 16 steel construction product groups. The products selected are considered by the project team to provide comprehensive coverage of the full range of steel construction products commonly manufactured and used in The Netherlands, United Kingdom and Sweden. Thirteen of these product groups are building components and thus relevant to use in this research. In figure 1 these product groups are illustrated, alongside an estimation of their volumetric impact in cubic meters per product group for each case study building. The greater the volumetric impact of a component suitable for reuse, the more it enhances the potential for reuse. This is because there are more identical elements available for design, and reusing more elements leads to greater environmental savings. It is important to note that the data from the figure is based on rough calculations and estimations due to the absence of essential drawings. Therefore it is possible that the voluminous impact in reality is higher than indicated here. In preparation for the acquisition of reused elements by developers, precise data is needed and a more comprehensive investigation would be required; in the context of developing a reuse assessment method, an indication of voluminous impact can be sufficient.

Figure 1 indicates which steel elements are more and less frequently encountered in the case study buildings. EWI has 19.000 m2 of window surface, involving the 21-story high-rise and the 250-meter-long low-rise being fully covered with a steel-curtain wall system, explaining the high voluminous impact of façade support and window frames. The high voluminous impact of services is a result of windows being replaced by ventilation grilles and dummy grilles, accounting for 370 m2 of facade area respectively. EWI has a concrete main structure, supported by heavy steel beams, columns, and reinforcement bars, surrounded by in-situ cast concrete. TN has also a concrete main structure, however, the superstructure uses a steel main structure and has profiled decking as roof support. TN has approximately 7200 m2 of window surface with steel window frames. The ground floor of TN partly consists of a composite floor decking system. GS is smaller than TN and EWI and instead of a concrete main structure, it has a steel main structure and lintels carrying the load of brickwork. The high voluminous impact of steel staircases and railings of GS is a result of all the balustrades inside the building. In Appendix A figure 1, additional information can be found about the case study buildings.

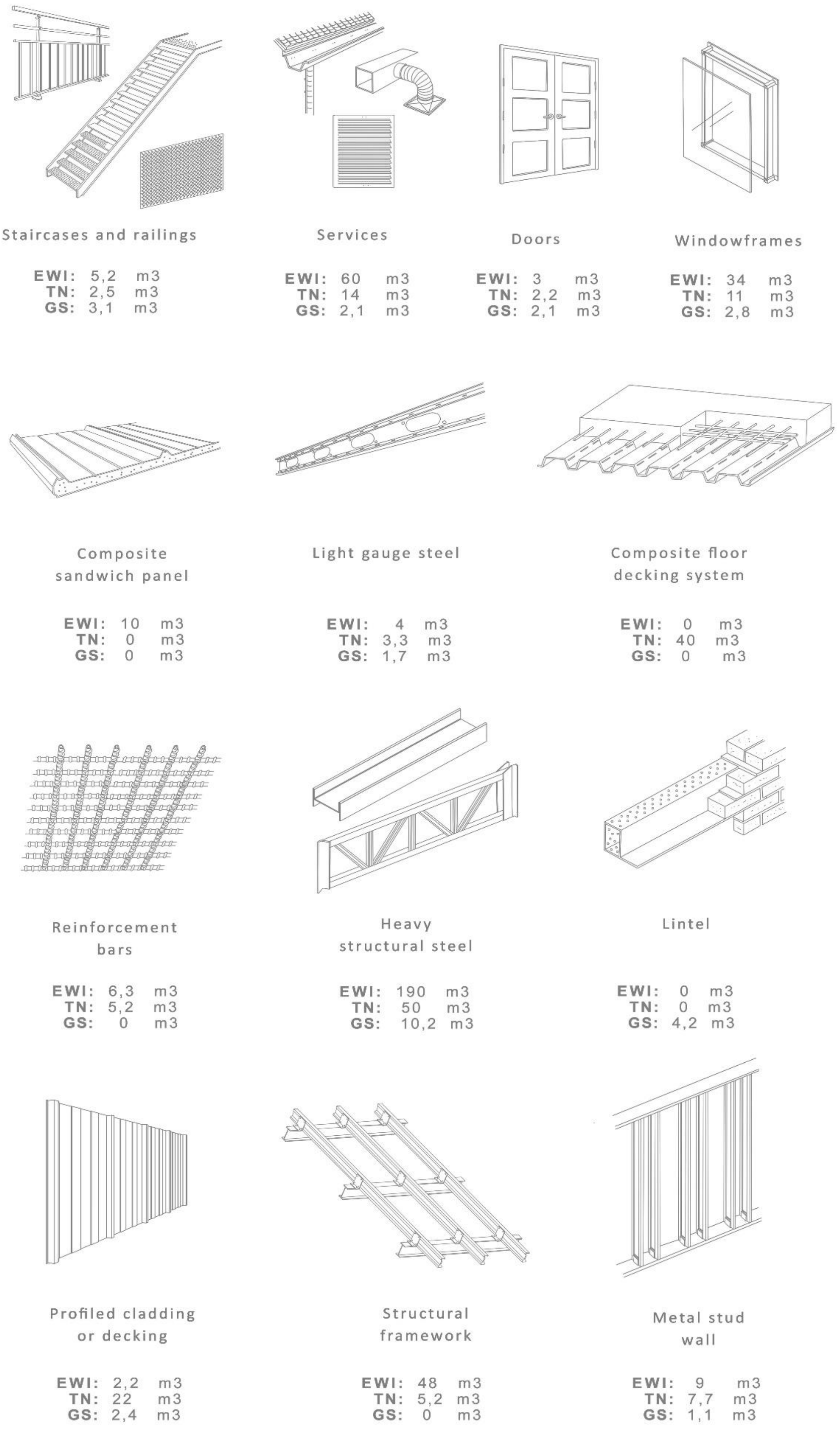


Figure 1; *Steel product groups and indication of volumetric impact per case study building*

II. FACTORS

The following chapters will delve into the factors that most significantly determine the reuse potential of a steel component. The product categories for steel components chosen in Chapter 1 are referenced in this context. The factors are categorized into three overarching themes: environmental impact, costs, and viability. It is important to note that factors are not isolated units but rather influence each other in multiple areas. This is why certain factors are mentioned in multiple themes.

2.1 Environment

This subchapter begins by explaining the environmental importance of reuse. It provides an introduction to the cyclic process of steel products, making it easier to comprehend the environmental impact of a steel product.

The research mentioned earlier in Chapter 1, the report titled "Life-cycle assessment (LCA) for steel construction from the European Commission (2003)," includes a detailed life cycle analysis of steel products in Western Europe, particularly in the Netherlands, Sweden, and the United Kingdom. In this analysis, the cyclic process is divided into 5 phases;

- Phase 1: Production of intermediate steel products
- Phase 2: Fabrication of finished steel products
- Phase 3: Construction
- Phase 4: In-use phase (maintenance)
- Phase 5: End-of-life phase

Specific activities included in these phases can be found in Appendix B figure 1. According to the LCA, the production of intermediate steel products, the fabrication of finished steel products, and maintenance are phases that, based on total CO_2 emissions (kg), waste (kg), and energy consumption (MJ) per phase, have the greatest environmental impacts. The comparison of emissions, waste production, and energy consumption per steel product group across phases can be found in Appendix B figure 2. This table demonstrates that, for each steel product group, production is by far the most polluting process.

Moreover, projections indicate a 30% increase in steel demand by 2050. Alongside emissions, there is a growing scarcity of raw materials. The escalating demand for new steel production puts pressure on the natural resources of coal and iron ore (Equify Financial, 2023). To reduce the amount of polluting production and conserve natural resources, approximately 60% of used steel across all industries is currently recycled into steel scrap (Björkman & Samuelsson, 2014). However, recycled steel scrap still needs to be processed into a finished intermediate product; a part of the recycling process thus occurs in the highly polluting phase 1. To understand the extent to which recycling and reuse impact the environment, it is crucial to examine the sub-processes. The research of Haas et al (2017) gives a typical overview of the process of reuse and recycling, shown in Appendix B figure 3. After eliminating all equivalent sub-processes, the system boundary for the recycling process model encompasses only the demolition, sorting, disposal, shredding, and steel mill processes. The sub-processes for reuse include only deconstruction, removal, transportation, and cleaning. A detailed version of these sub-processes can be found in Appendix B figure 4, which focuses on the emission-producing activities associated with each sub-process.

Where in the report of the European Commission the units of CO_2 emissions, energy consumption, and waste were used to measure the environmental impact, Haas et al uses greenhouse gasses (CO_2, CH_4 & N_2O, (t)), water withdrawals (m^3), and conventional air pollutants (t) to measure. When the pollution from the sub-processes is aggregated, it becomes apparent that reuse is the superior alternative in terms of the greenhouse gas values of carbon dioxide (CO_2), particulate matter (PM_{10}), sulfur dioxide emissions, carbon monoxide (CO), methane (CH_4), and nitrous oxide (N_2O), as well as for water withdrawal. The exact values for emission reduction for steel reuse compared to recycling are listed in Appendix B figure 5.

Geyer et al. (2015) even suggests that new steel structures with approximately 60% recycled content have an environmental impact 25 times higher than reusing an equivalent amount of reclaimed steel. Approximately 60 percent of steel is recycled, however, more steel is produced than scrapped, thus recycled steel constitutes about 40 percent of the total amount of steel produced (The World Counts, 2023).

The higher the environmental impact of a steel product group, the more potential savings can be achieved through reuse, thus enhancing the product's reuse potential. The report by the European Commission provides highly detailed environmental impact data for each product group, calculated using various methods, including the BRE method and Eco-Quantum B. Unfortunately, product groups were calculated in different units, making it challenging to determine which product groups have a higher or lower impact. Therefore, the decision was made to determine the environmental impact through EPD sheets. An EPD is an environmental label and stands for Environmental Product Declaration. The foundation is formed by a LCA of a product (Allen et al, 2023). Manufacturers can input the EPD calculation into the Nationale Milieu Database (NMD), based on which the Milieu Prestatie Gebouwen (MPG) is determined for every new building. Bouwen met Staal (2004) released EPD values for the five different production processes of intermediate steel products. The steel product groups from the European Commission's report can be categorized within these values (Appendix B figure 6 & 7). In an EPD calculation, the environmental impact per tonne steel product is measured in greenhouse effect, toxicity to humans, abiotic exhaustion, ecotoxicity of water (fresh water), ecotoxicity of sediment (fresh water), terrestrial ecotoxicity, acidification, over fertilisation, photochemical oxidant formation and ozone layer depletion. Figure 2 shows the EPD results per product group. These EPD results are relatively high compared to EPD's from other building materials like concrete, wood and synthetics. For further comparison, in Appendix B figure 8 the EPD results of Portland Cement are included, the component in concrete being most responsible for its poor environmental performance.

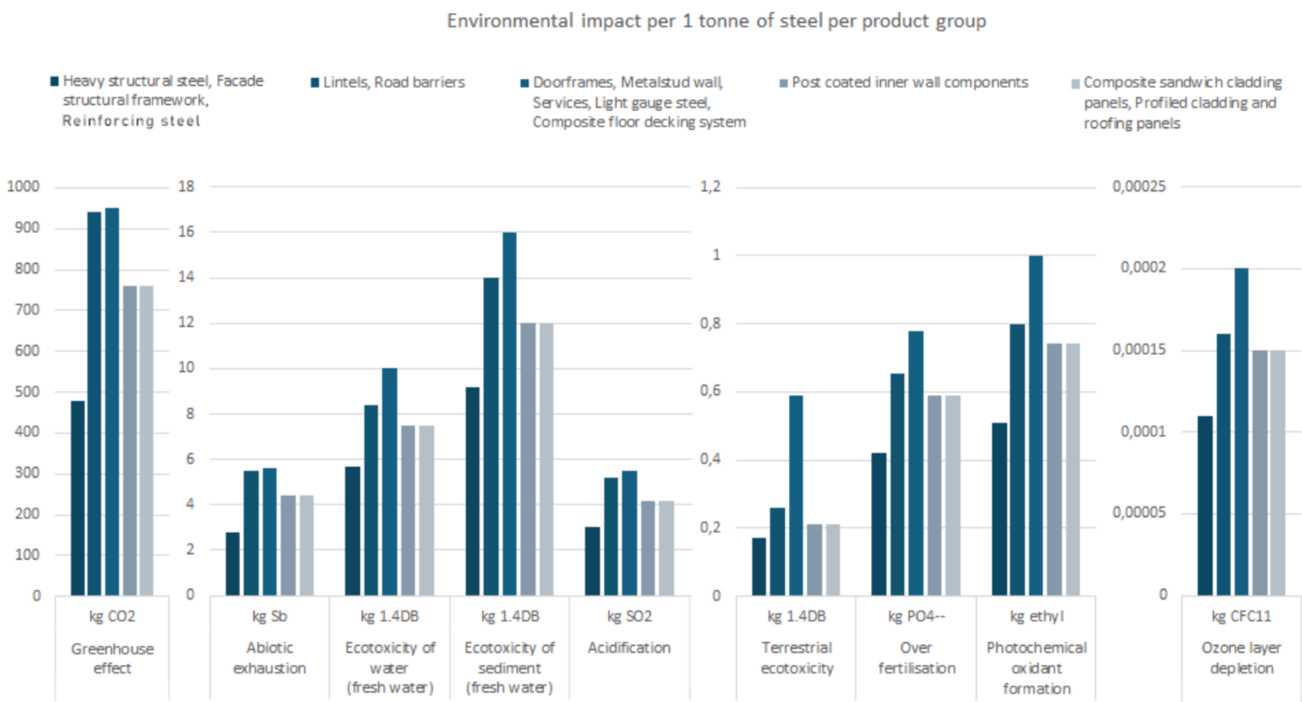


Figure 2; *Environmental impact per 1 tonne of steel per product group (Based on Appendix B fig. 6 & 7)*

Because phase 1 of the production process is most determining for the environmental impact of a product group, the EPD is reasonably representative of the product group, but it remains only an indication. For more recent and detailed EPD analyses of the selected product groups, there is an online international EPD database available. Unfortunately, some steel product analyses are revised periodically, and this data was not available for this research.

2.2 Costs

MKIs (Milieu Kosten Indicator) represent the shadow costs of a product, which are then applied in the calculation for the MPG. In an MKI, the environmental impact is calculated through an LCA, after which results are linked to a monetary value (€). MKIs are particularly important for new and recycled steel products, where the history of the product is known (Quist, 2023). When reusing steel, the history of the product is often not yet known, and the quality must be determined through costly inspections. Nowadays, more and more companies are beginning to register the MKI of newly produced steel in the Nationale Milieudatabase, so that in the future steel components can be reused without most of these inspections. Until then, reuse is not always cheaper than the usual cycle (Verwoolde Beeld, 2023). The eliminated sub-processes, discussed in chapter 2, for recycling and reuse respectively, show how much labour and machinery are involved in the recycling process; yet, this is often the cheaper route (see Appendix B figure 4).

The challenge of reusability is linked to the procurement of appropriate elements in sufficient quantities during the design phase. The time required to identify and buy components is crucial for achieving cost savings (Kernan, 2002). Unfortunately, the European market for second-hand elements is small. As a result, there is a lack of recovery facilities for reused elements and information about available components from planned and ongoing demolition works. For heavy structural steel, composite sandwich cladding panels, and profiled cladding and roofing panels, there are already firms that have some products ready for reuse in storage. Components like window/door frames and metal stud walls, as well as purlins and rails, are usually only available when directly purchased from a donor building (Hradil et al, 2019).

In the case of steel products with a low market value, the economic incentive for reuse may be low or negative due to the costs associated with careful removal, as suggested by Hobbs & Adams (2017). Companies specializing in deconstruction for reuse are rare, making labour more expensive. However, if an element can be quickly dismantled, costs could be reduced. Regarding the ease of disassembly of steel components, see next chapter 'Longevity.'

Furthermore, the steel product must undergo thorough inspections to assess whether the quality meets the same safety requirements as for new steel, as documented in the Dutch 'Bouwbesluit' (Nationale Milieudatabase, 2023). Conducting inspections is one of the most escalating costs. Inspections have to be carried out by specialists who have the appropriate testing equipment, and permits must be obtained for the application of certain products. In 2023, a Dutch guideline for inspections has been introduced for structural steel. This NTA (Nederlands Technische Afspraak) assists in the creation of an inspection document to verify whether the reusable steel complies with the Bouwbesluit and NEN-EN 1993 (National Environmental Database, 2023). However, there is currently no guideline for inspections regarding other steel uses.

Some inspections hold more significance than others; if the strength of the steel no longer meets standards, the product is unsuitable for reuse. In the case of inadequate water tightness, it may still be addressed through upcycling: involving the enhancement of the product's quality. It is often the case that the more a product can endanger the safety of a user, the more inspections including expensive equipment, the more the costs, thus negatively affecting the reuse potential (Hradil et al, 2019). The execution of inspections is not specifically dependent on the type of steel product group but rather on its new application and use in a construction project. Assuming conventional reuse, the figure below illustrates the degree of inspections per product group. Different colours indicate inspection categories that involve higher specialization and costly testing methods (red). For a detailed overview of testing methods of the more expensive inspection categories, refer to Appendix C figure 1.

Importance of inspections:							
Inspections per steel product group	Structural safety	Fire safety	Wind load requirements	Waterproofing standards	Thermal insulation criteria	Sound insulation requirements	Dimensional specifications
Heavy Structural Steel	x	x	x				
Structural framework	x	x	x				
Lintels	x	x	x				
Reinforcement steel bars	x						
Composite floor decking system	x	x	x	x	x	x	
Light Gauge Steel		x	x				
Profiled cladding or decking		x	x	x			
Metal Studs walls or ceiling		x				x	
Composite sandwich panels		x	x	x	x	x	
Doorframes (exterior/interior)				x	x		x
Windowframes				x	x	x	
Staircases and railings (interior)	x	x					x
Services (drainage/ventilation)			x	x			

Figure 3; *Inspections per steel product group and its importance (Based on Appendix C fig. 1)*

Finally, the location of harvesting, storage, and application is important. One of the advantages of local harvesting is that transportation costs are low. Besides, the compactness level of a product is important, since more products can be transported with the same vehicle. Depending on the storage location, it can be more expensive (urban areas) or cheaper (provincial, rural areas). Additionally, the time between harvesting and application is crucial for storage costs (Gorgolewski, 2008).

2.3 Longevity

The lifespan of steel products is currently inherent to the relatively short service time of some buildings. Steel products are mostly under-exploited, since the degradation process is much slower than other building materials. With the correct maintenance, some steel elements can be used for 150-200 years (Cooper et al, 2014). Longevity itself is not considered a factor directly influencing the reuse potential, it rather functions as an overarching theme formed by several influential factors; performance, condition, defects, coating and the ability to dismantle for reuse after the service time of a building (Birhane et al, 2023).

Dismantling refers to the process by which a building is selectively taken apart, where specific components are carefully removed with the aim of reusing certain or all of its parts. Ease of dismantling is an important factor in terms of reuse potential. If the process of dismantling a component is challenging, it can lead to increased costs for reuse and there is a heightened risk of severe damage to the components, significantly reducing their potential for reuse. The ease of dismantling depends upon the type of connection between two components of a component group and the assembly hierarchy between multiple elements of this component group (Durmirsevic, 2003). The types of connections vary between four categories; direct and indirect, internal and external connections. Direct connections involve components that are attached to each other in such a way that they can transfer forces directly when a component moves. In indirect connections, forces first pass through the connecting material. The internal type incorporates an connection inserted into or in between the two components, often with the aim of achieving a neat-looking finish. With an external accessory, bolts and nuts or other fixation devices are visible from the outside, and these are just a bit easier to loosen. In figure 4 variations of these four categories are arranged based on the degree of impact on the reuse potential of a component. Direct internal chemical connections, such as welding or gluing, have a negative impact, whereas indirect external connections significantly enhance the potential. On the horizontal axis, the assembly hierarchy between multiple components of a component group is depicted. A 'layered' assembly indicates a sequential arrangement, introducing dependencies between assembled elements and complicating the substitution process. An 'open' assembly involves a parallel arrangement, significantly speeding up the dismantling process. At the forefront is the 'stuck' assembly, where multiple components are dependent in various ways, resulting in a prolonged dismantling process. The table indicates several steel product groups with relatively standard types of internal connections, such as connections in a conventional door frame and a metal stud wall. For other product groups, there are often multiple options regarding the type of connections, and the connection will therefore need to be assessed on-site. The figure is based on a compilation of data from E. Durmirsevic's research; "Transformable building structures: for disassembly as a way to introduce sustainable engineering to building design & construction" (2006). In Appendix D her original figures can be found, including examples of the connection types.

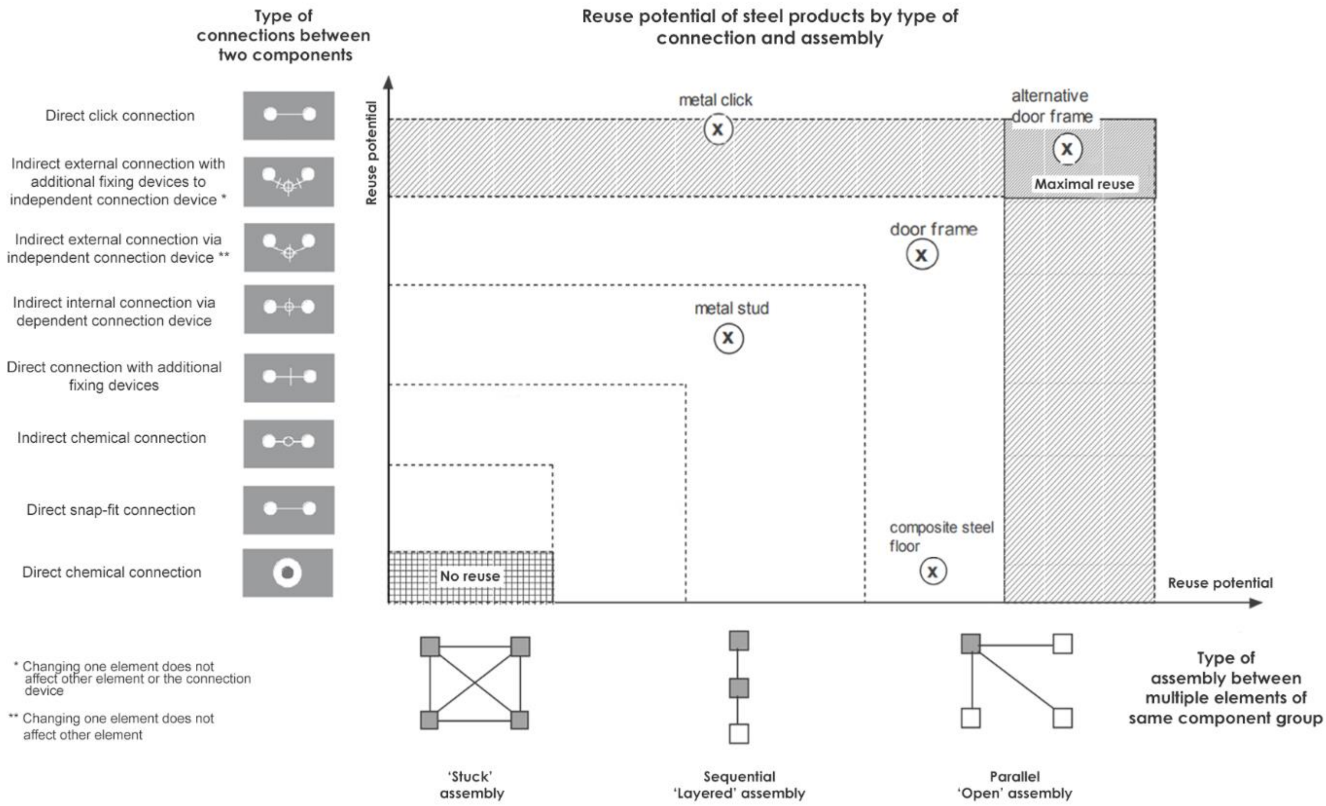


Figure 4; *Reuse potential of steel products by type of connection and assembly (Based on Appendix D; Durmirsevic, 2006)*

Where dismantling often requires only a visual inspection, determining performance and defects, often necessitates a more thorough inspection with special equipment. When it comes to the performance of a steel component, it involves strength, stiffness, and hardness. Strength refers to the degree to which a material can withstand applied forces without permanent deformation or fracture, stiffness is the degree of elasticity under deformation, and hardness is the resistance to deformation under a point load (NTA Hergebruik Staal, 2023). Through destructive testing (DT) and non-destructive testing (NDT), these factors are measured to determine the safety in case the steel component will be reused. NDT’s keep the material intact but are often more expensive than DT’s. An example of a DT to determine hardness is to press a diamond indenter into the component to measure the Vickers value, for which an ultrasonic hardness meter would be used in a NDT. Furthermore, it is important to examine the chemical composition of the component. Other materials than steel may be encountered that are not easily visible, such as welding material. A portable optical emission spectrometer (NDT) measures the carbon equivalent (CEq) and weld crack sensitivity, negatively affecting the hardness of a material (Fujita & Kuki, 2016). When it comes to defects, it involves bends, dents, cracks, and holes, whether visible or invisible to the naked eye. For internal defects, ultrasonic testing can be conducted to assess their severity. The condition refers to the surface condition of the material, often dependent on the degree of rust formation (Birhane et al., 2023). Rust is the corrosion process where iron on the surface of a steel component oxidizes, and this can weaken the component if left untreated. To prevent degradation due to rust, various protective measures are applied, including the application of coatings, galvanizing (applying a thin layer of zinc), rust-resistant paints, and regular maintenance (Marder, 2000). Coatings can also be important for fire safety. Often used coatings are paint coatings based on epoxies or polyurethanes, or powder coatings. When assessing rust formation and coatings, a visual inspection is often sufficient. In case of uncertainty, the effectiveness of the preservation can be measured through methods such as magnetic thickness measurement (NDT) or salt spray testing (DT) (IGOS, 2023).

Independent of the concept of longevity but partly dependent on similar factors, there is also aesthetic value. This is a subjective factor. The type of coating, the amount of rust and defects, and the appearance of connections can influence the aesthetical value of steel components. Aesthetic value is often high in elements with monumental significance; characteristic features from a particular (time) period (Goldman, 1990).

Often, one representative component from a component group is chosen to test, to save time. A component is considered representative for its group, when it comes from the same manufacturer and production period, has experienced similar forces and has been under similar weather conditions.

III. Value Assessment

In the value assessment, the steel product groups from the case study buildings are categorized and measured against the factors influencing their reuse potential. In table 1 (EWI), table 2 (TN), and table 3 (GS), the factors discussed in the previous chapters can be found under their main themes. It is noteworthy that ‘ease of dismantling’ is placed under costs, and ‘demountability’ under longevity. Distinguishing these is important, as a component may be demountable but dismantling it may be labour-intensive and requires expensive, heavy machinery to effectively remove it from the building. Additionally, aesthetic value is placed under longevity to keep the table organized, but as the only subjective factor among the objective ones, it should actually be considered a separate main theme. The tables below provide a simplified overview of the tables found in Appendix E figure 1, 2 & 3. The rating consists of three values, where red indicates a negative, yellow a neutral, and green a positive impact on the reuse potential. Slashes indicate that a steel product group is not or hardly represented in the building or that the reuse of a product is not influenced by a certain factor. For example, a coating may not be present because it was not needed or because it concerns stainless steel. Furthermore, crosses are placed under performance and defects because the impact of these factors cannot be determined without the assistance of special measuring equipment, which was not available for this research. When filling in the value assessment, it was assumed that elements from the case study buildings were reused in new construction on campus, to align with the plans in the Sustainable Vision of TU Delft. Considering that the TU has sufficient storage space, transportation occurs on a local scale, and supply and takeover are handled by the same entities, the product groups only have positive values for these factors.

Given that the environmental impact of steel elements is already relatively high compared to other building materials, which would result in a monotonous valuation, the assigned value here is determined by comparing steel EPD’s to each other. This demonstrates on an environmental level which steel products in a building are more interesting to reuse than others. In terms of volumetric impact, a high or low value of the voluminous impact (m^3) of a product is determined relative to the total steel volume per case study building. In case the value assessment is not per building, and the amount of steel in the three buildings should be compared, it is more convenient to measure the volume in tons/m^2 GFA. It is important that environmental impact is considered in combination with volumetric impact to determine the reuse potential more accurately. Heavy structural steel, due to its higher reuse and recycling percentage, has a lower EPD value than other steel products but exceeds in terms of volume, thus having a neutral and positive value in the table. Window frames are only having positive ratings in this area. However, the total environmental impact of heavy structural steel is higher than that of window frames. Furthermore, it may be that reusing elements with a high environmental impact can yield certain economic benefits, such as through the subsidieregeling circulaire economie (SCE), Milieu-investeringsaftrek (MIA) and Willekeurige afschrijving milieu-investeringen (Vamil) (Rijksdienst voor Ondernemend Nederland, 2024). Therefore, depending on its application and corresponding subsidies, reusing heavy structural steel may result in lower costs than other product groups, although the values in the table indicate otherwise.

Value assessment steel product groups EWI	Environment		Costs					Longevity					
	Volumetric impact	Environ-mental impact	Procure-ment	Inspec-tions	Ease of dismant-ling	Storage	Transport	Demoun-tability	Perfor-mance	Condition	Defects	Coating	Aesthetical value
Heavy Structural Steel	✓	!	✓	✗	✗	✓	✓	✗	x	✓	x	!	✓
Structural framework	✓	!	✓	✗	!	✓	✓	✓	x	✓	x	!	!
Lintels	/	/	/	/	/	/	/	/	/	/	/	/	/
Reinforcement steel bars	✓	!	✓	✗	✗	✓	✓	✗	x	!	x	/	/
Composite floor decking system	/	/	/	/	/	/	/	/	/	/	/	/	/
Light Gauge Steel	✗	✓	✓	!	!	✓	✓	✓	x	✓	x	✓	✓
Profiled cladding or decking	!	!	✓	!	✓	✓	✓	✓	x	!	x	!	!
Metal Studs walls or ceiling	✗	✓	✓	!	✗	✓	✓	✗	x	/	x	✓	/
Composite sandwich panels	!	!	✓	!	✓	✓	✓	✓	x	✓	x	✓	✓
Doorframes	!	✓	✓	✓	✓	✓	✓	✓	x	✓	x	!	!
Windowframes	✓	✓	✓	✓	✗	✓	✓	✗	x	!	x	!	!
Staircases and railings	!	!	✓	✗	!	✓	✓	✓	x	!	x	!	!
Services	!	✓	✓	!	!	✓	✓	!	x	!	x	/	✗

Table 1; *Value Assessment of steel components EWI*

Value assessment steel product groups TN	Environment		Costs					Longevity					
	Volumetric impact	Environ-mental impact	Procure-ment	Inspec-tions	Ease of dismant-ling	Storage	Transport	Demoun-table	Perfor-mance	Condition	Defects	Coating	Aesthetic value
Heavy Structural Steel	✓	!	✓	✗	!	✓	✓	!	x	✓	x	✓	✓
Structural framework	!	!	✓	✗	!	✓	✓	✓	x	✓	x	!	!
Lintels	/	/	/	/	/	/	/	/	/	/	/	/	/
Reinforcement steel bars	!	!	✓	✗	✗	✓	✓	✗	x	✓	x	!	/
Composite floor decking system	✓	✓	✓	✗	✗	✓	✓	✗	x	✓	x	✓	/
Light Gauge Steel	✗	✓	✓	!	✓	✓	✓	✓	x	✓	x	✓	✓
Profiled cladding or decking	✓	!	✓	!	✓	✓	✓	✓	x	!	x	!	✓
Metal Studs walls or ceiling	!	✓	✓	!	✗	✓	✓	✗	x	✓	x	✓	!
Composite sandwich panels	/	/	/	/	/	/	/	/	/	/	/	/	/
Doorframes	✗	✓	✓	✓	✓	✓	✓	✓	x	✓	x	✓	✓
Windowframes	!	✓	✓	✓	✗	✓	✓	✗	x	!	x	!	!
Staircases and railings	✗	!	✓	✗	!	✓	✓	!	x	✓	x	✓	✗
Services	!	✓	✓	✓	✓	✓	✓	✓	x	!	x	/	✓

Table 2; *Value Assessment of steel components TN*

Value assessment steel product groups GS	Environment		Costs					Longevity					
	Volumetric impact	Environ-mental impact	Procure-ment	Inspec-tions	Ease of dismant-ling	Storage	Transport	Demoun-table	Perfor-mance	Condition	Defects	Coating	Aesthetic value
Heavy Structural Steel	!	!	✓	✗	✗	✓	✓	✗	x	✗	x	✗	!
Structural framework	/	/	/	/	/	/	/	/	/	/	/	/	/
Lintels	!	!	✓	✗	✗	✓	✓	✗	x	✗	x	✗	✗
Reinforcement steel bars	/	/	/	/	/	/	/	/	/	/	/	/	/
Composite floor decking system	/	/	/	/	/	/	/	/	/	/	/	/	/
Light Gauge Steel	✗	✓	✓	!	!	✓	✓	!	x	!	x	✗	✗
Profiled cladding or decking	✗	!	✓	!	✓	✓	✓	✓	x	✗	x	✗	✓
Metal Studs walls or ceiling	✗	✓	✓	!	✗	✓	✓	✗	x	!	x	✗	✗
Composite sandwich panels	/	/	/	/	/	/	/	/	/	/	/	/	/
Doorframes	✗	✓	✓	✓	✓	✓	✓	✓	x	!	x	!	✓
Windowframes	✗	✓	✓	✓	✗	✓	✓	✗	x	!	x	!	✓
Staircases and railings	!	!	✓	✗	!	✓	✓	!	x	!	x	!	✓
Services	✗	✓	✓	✓	✓	✓	✓	✓	x	✗	x	/	✗

Table 3; *Value Assessment of steel components GS*

Some factors are fixed; when a steel product no longer meets the requirements in terms of performance or defects, it immediately fails to meet the criteria of conventional reuse. Perhaps a suitable repurpose can still be found. Some factors are flexible; when there is a high budget available and all deteriorated coatings can be replaced, it reduces the impact of the factor ‘coating’ on the reuse potential. If these factors have a negative impact, conventional reuse is not necessarily ruled out; this often depends on time and budget. A decision chart balancing fixed and flexible factors for some steel products has been prepared, which can be found in Appendix E figure 4.

Overall, components most suitable for conventional reuse according to the value assessment of EWI are steel profiled cladding or decking, doorframes and composite sandwich panels. Also service systems are still suitable for reuse, although ventilation grilles on the façade show some slight wear and tear. Structural framework can be interested to reuse, depending on budget. Heavy structural steel, reinforcement bars and steel window frames are due to its high costs for reuse and stuck assembly, an unfavourable choice for reuse. The value assessment of TN shows that the heavy structural steel of this building, especially found in the superstructure, is suitable for reuse. Besides, light gauge steel, structural framework and service systems have a high reuse potential. Also profiled floor decking and cladding can be interesting to reuse, although a new coating should be applied. Lastly, the staircases and railings, including thread and raster plates, interior doors and characteristic windows of partition walls of GS, are suited for reuse. Here it is highly unfavourable to reuse heavy structural steel and lintels.

CONCLUSION

To conclude on the research question; ‘How can reclaimed steel elements from TU Delft’s outdated campus buildings be assessed for component reuse?’, it is important to identify all the factors influencing the reusability potential of a steel component. Divided into the three main themes environment, costs and longevity, these factors are volumetric and environmental impact, procurement, inspections, ease of dismantling, storage and transport, demountability, performance, condition, defects, coating and aesthetical value. In a value assessment, these factors are measured against thirteen steel product groups common in Western Europe in which components found in the case study buildings are categorized. The more factors a steel product scores positively on, the more suitable the component is for reuse. It is important to notice that factors can be distinguished as flexible and fixed. Often depending on time and budget of a project, the level of influence of a flexible factor on the reuse potential may vary.

References

Agudelo-Vera, C. M., Leduc, W. R. W. A., Mels, A. R., & Rijnaarts, H. H. M. (2012). Harvesting urban resources towards more resilient cities. Resources, Conservation and Recycling, 64, 3-12. https://doi.org/10.1016/j.resconrec.2012.01.014 Alaka, H., Charef, R., Morel, J., & Rakhshan, K. (2020). Components reuse in the building sector: A systematic review. Waste Management & Research, 38(4), 347-370. DOI: 10.1177/0734242X20910463

Alaka, H., Charef, R., Morel, J., & Rakhshan, K. (2020). Components reuse in the building sector: A systematic review. Waste Management & Research, 38(4), 347-370. DOI: 10.1177/0734242X20910463

Allen, S., Hattam, L., & Marsh, E. (2023). Tackling uncertainty in life cycle assessments for the built environment: A review. *Building and Environment, 231*, 109941. https://doi.org/10.1016/j.buildenv.2022.109941

Bender, A.P., Bilotta, P. (2019). Circular Economy and Urban Mining: Resource Efficiency in the Construction Sector for Sustainable Cities. In: Leal Filho, W., Azul, A., Brandli, L., Özuyar, P., Wall, T. (eds) Sustainable Cities and Communities. Encyclopedia of the UN Sustainable Development Goals. https://doi.org/10.1007/978-3-319-71061-7_40-1

Birhane, M., Fishwick, R., Kanyilmaz, A., et al. Reuse of Steel in the Construction Industry: Challenges and Opportunities. Int J Steel Struct 23, 1399–1416 (2023). https://doi.org/10.1007/s13296-023-00778-4

Björkman, B., & Samuelsson, C. (2014). Recycling of steel. In *Handbook of recycling;* State-of-the-art for Practitioners, Analysts, and Scientists. (pp. 65-83). Elsevier.

Blom, T., & Van den Dobbelsteen, A. (2019, July 25). CO2-roadmap TU Delft. Finale versie 2.9_190725. TU Delft, Faculteit Bouwkunde, Afdeling Architectural Engineering + Technology, Leerstoel Climate Design & Sustainability

Cembureau. (2020). Environmental Product Declaration (EPD) according to EN 15804 and ISO 14025: Portland Cement (CEM I) produced in Europe.

Cooper, D. R., Allwood, J. M., Moynihan, M. C., & Skelton, A. C. (2014). Component level strategies for exploiting the lifespan of steel in products. *Resources, Conservation and Recycling, 84*, 24-34.

Durmirsevic, E. (2006). Transformable Building Structures; Design for disassembly as a way to introduce sustainable engineering to building design & construction. Proefschrift voor verkrijging van doctoraat, Delft University of Technology, Netherlands.

Durmirsevic, E. & Noort, N. (2003). Reuse potential of steel in building construction. Delft University of Technology, department of Building Technology, Netherlands.

Duurzaam in staal. (2004). EDP sheet of Steel production groups. Via Bouwen met Staal. https://www.sustainableinsteel.eu/p/534/the_lca_of_steel.html

Equify Financial. (2023). The Steel Shortage, Rising Prices, and How It Affects the Equipment Market: The reality of the Steel Shortage. Blog on Equify Financial.https://www.equifyfinancial.com/blog/article/the-steel-shortage-rising-prices-andhow-it-affects-the-equipment-market

European Commission, Directorate-General for Research and Innovation, Sansom, M., Meijer, J. (2002). *Life-cycle assessment (LCA) for steel construction : final report*, Publications Office.

Frisse Wind Nu!. (2023). Feiten & cijfers over de impact van Tata Steel. Cijfers via RIVM. Via https://www.frissewind.nu/ feiten-over-tata-steel

Fujita, M., & Kuki, K. (2016). An Evaluation of Mechanical Properties with the Hardness of Building Steel Structural Members for Reuse by NDT. Metals, 6(10), 247. https://doi.org/10.3390/met6100247

Gameren, D., & Van den Dobbelsteen, A. (2022). Sustainable Vision: Ambition and Action Plan for a Climate University. Via https://research.tudelft.nl/ Gameren, D. & van den Dobbelsteen, A., (2023). The Sustainable Campus: Working towards a Carbon-Neutral University. In Measuring Net Zero: Carbon accounting for buildings and communities. Roaf, S. & Finlayson, W. (eds.). Ecohouse Initative Ltd, p. 273-285 12 p.

Geyer, R., Henderson, A., Kuczenski, B., & Zink, T. (2015). Common Misconceptions about Recycling. *Journal of Industrial Ecology*, 20(5), 1010–1017. https://doi.org/10.1111/jiec.12355

Goldman, A. H. (1990). Aesthetic Qualities and Aesthetic Value. *The Journal of Philosophy*, *87*(1), 23–37. https://doi.org/10.2307/2026797

Gorgolewski, M.(2008). Designing with reused building components: some challenges. Building Research & Information, 36:2, 175-188, DOI: 10.1080/09613210701559499

Haas, C., Walbridge, S., Yeung, J., et al. (2017). Understanding the total life cycle cost implications of reusing structural steel. *Environmental Systems and Decisions*, 37, 101–120. https://doi.org/10.1007/s10669-016-9621-6

Hobbs, G. & Adams, K. (B017). Reuse of building products and materials – barriers and opportunities. International HISER Conference on Advances in Recycling and Management of Construction and Demolition Waste.

Hradil, P., Sansom, M., Ungureanu, V., & Vares, S. (2019). Economic potential and environmental impacts of reused steel structures. *Structure and Infrastructure Engineering: Maintenance, Management, Life-Cycle Design and Performance, 16*(4), 750–761. https://doi.org/10.1080/15732479.2019.1664055

IGOS. (2023). Coating Thickness Measurement: destructive and non-destructive measuring techniques. Via https://www.igos.de/en/services/coatings-analyses/coating-thickness-measurement

Kernan, P. (2002). Old to New Design Guide: Salvaged building materials in new construction. Greater Vancouver Regional District Policy & Planning Department

Marder, A. R. (2000). The metallurgy of zinc-coated steel. *Progress in materials science*, *45*(3), 191-271. Elsevier.

Nationale Milieudatabase. (October, 2023). NTA-8713 hergebruik van staal voorziet in een behoefte. https://milieudatabase.nl/nl/actueel/nieuws/nta-8713-hergebruik-van-staal-voorziet-in-een-behoefte

NTA Hergebruik Staal [werkgroep]. (2023, June). Nederlands Technische Afspraak (NTA) 8713. Hergebruik van constructiestaal. Via Stichting Koninklijk Nederlands Normalisatie Instituut (NEN).

Posad Maxwan & TU Delft CRE. (2019). Concept 5.0: TU Delft Campus Zuid stedenbouwkundig plan. https://www.tudelftcampus.nl/wp-content/uploads/2021/08/190606_Eindrapport_SP_TU_Delft_Campus_Zuid_CONCEPT_5.0_screen.pdf

Quist, Z. (2023). Wat zijn schaduwkosten? Milieu impact en LCA. Via Ecochain. https://ecochain.com/nl/blog/wat-zijn-schaduwkosten/

Rijksdienst voor Ondernemend Nederland. (2024). Gebouwde omgeving en MIA\Vamil. Via https://www.rvo.nl/subsidies-financiering/mia-vamil/ondernemers/gebouwde-omgeving

The World Counts. (2023). Tons of steel recycled. https://www.theworldcounts.com/challenges/planet-earth/mining/advantages-of-recycling-steel

Verwoolde Beeld, L. (2023). MKI behoort tot de laagste van Nederland. Beton&Staalbouw. Van Ee staalspecialisten. https://www.betonenstaalbouw.nl/artikel/mki-behoort-tot-de-laagste-van-nederland

APPENDIX A – CASE STUDY DATA

Figure 1 : Map of TU Delft Campus North with the case study buildings in red

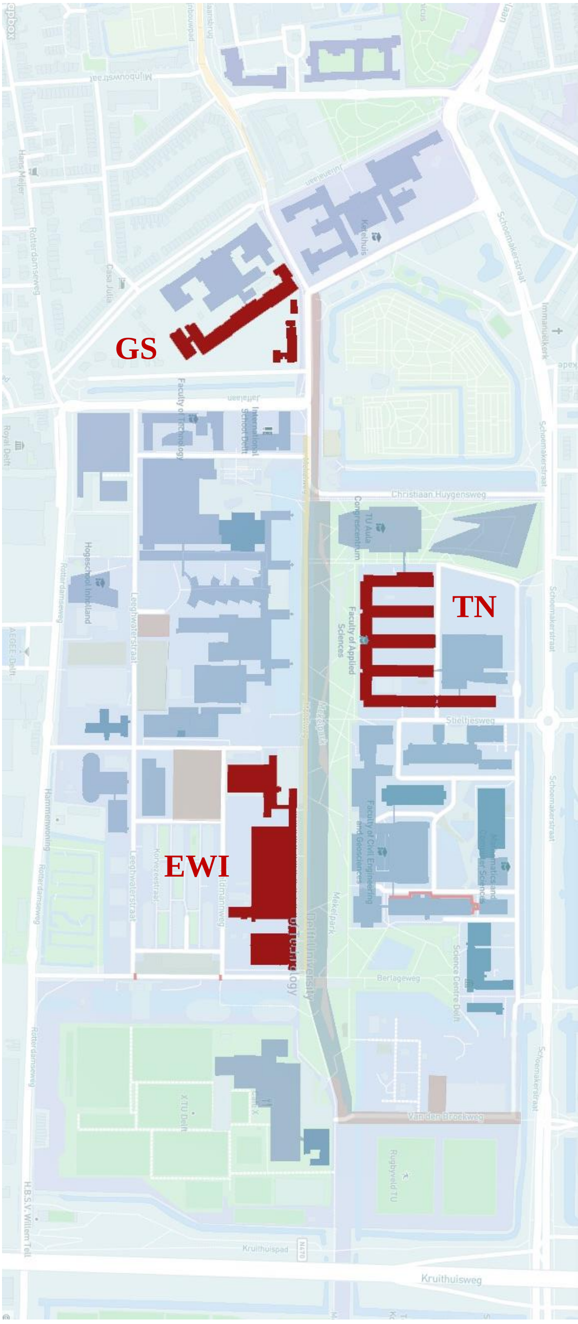


Figure 2 : Additional information case study buildings EWI, TN and GS

Picture 1; EWI *(Dylunio Architectuur, 2024)*

EWI has **19.000 m^2 of window surface**, consisting of single and double glazing in steel window frames, connected to an extensive framework of vertical and horizontal steel profiles. Both the **21-story high-rise** and the **250-meter-long low-rise** are fully covered with this **steel-curtain wall** system on the North-East and South-West sides. During the construction of EWI, double glazing was still in development and, moreover, expensive. Only the low-rise has some double glazing on the west facade. In the other parts, the fastening and sealing material putty, holds the single glazing and Colourbel glass in place in the steel frames. In vertical stripes on the facade, the glass has been replaced with steel **ventilation grilles** and dummy grilles, accounting for 200 m^2 and 170 m^2 of facade area, respectively. The façade structural support, mainly vertical IPE 80 and horizontal H100 profiles, are attached with bolts to steel anchors embedded in the concrete floors. Whether it is about renovation or demolition of EWI, the entire steel-curtain wall needs to be replaced with a sustainable and fire-resistant alternative. The concrete main structure is supported by steel beams, columns, and reinforcement steel, surrounded by in-situ cast concrete. Another part of EWI that contains many steel components is the **high-voltage hall**, but it has received the national steel award for its sustainable renovation and, therefore, will no longer be considered for demolition or renovation.

Picture 2; Technische Natuurkunde (Heidarian, 2019)

Concrete is the most commonly used construction material in **TN**, with **reinforcement steel** playing a significant role. The ground floor consists of a so-called steel plate super floor, meaning in-situ poured concrete on top of a thick corrugated steel layer. Similar to EWI, **steel windows** with single glazing were applied. These rectangular steel frames can be found in the facade of the entire building, except for the superstructure. The steel window assembly in the main block accounts for 2400 m^2 of façade and if the wings are included, this surface area becomes many times larger. Corrugated steel cladding has been applied in the facade under certain window assemblies for aesthetic reasons. TN has a **superstructure**, consisting of the third floor of Wing E on the southeast side and the fourth floor of the main block on the southwest side. This elongated superstructure has a **steel main structure**, with heavy beams such as IPE 220 and IPE 200 profiles, backed up by HE-180-A/HE-140-A profiles. The superstructure mainly comprises offices separated by **metal stud walls** between steel square tube profiles. The roof consists of **corrugated steel** decking with insulation on top. A false ceiling is attached to small steel profiles, concealing a ventilation system made of steel pipes.

Picture 3 ; Gele Scheikunde (Eigen afbeelding)

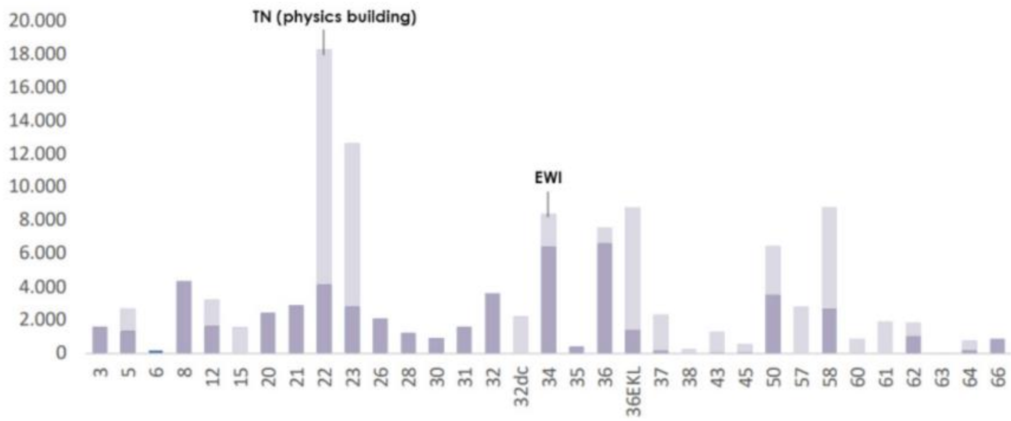
GS consists largely of steel elements. General European designations for profiles did not exist yet at the time of construction. Some profiles are indicated by the Differdingerse standard (such as DIE and DIN, predecessors of HEA and HEB), and some follow the German standard (such as INP, predecessor of IPE). The construction of the outer walls consists of steel INP 340 columns between which **steel lintels** are attached, carrying the weight of the brick wall to the main structure. Steel frames have been used for the single-glazed windows in the facade. Inside, there is a large, **extensive steel balustrade** spanning two floors. This balustrade is entirely composed of DIE columns and INP/UNP beams, with floors of alternately poured concrete, perforated steel plates or tread plates, and steel railings. Inside the tall tower, there are **steel stairs, railings, and grid plates** as floors. UNP profiles have been used as roof gutters.

Figure 3 : Goals for new buildings in Sustainable Vision 2022 (Gameren & Van den Dobbelsteen, 2022)

Circulair		Doel
Materiaalgebruik	X% van het materiaal is geoogst uit bestaande gebouwen	10% (Hangt van aanbod af)
Materiaalgebruik	X% van de vrijgekomen materialen vanuit TU Delft Campus worden hergebruikt in het gebouw	80%
Materiaalgebruik	X% van de gebruikte materialen in het gebouw zijn circulair (PM circulair -> definitie nodig)	80%
Materiaal registratie	X% van het gebruikte materialen/producten worden geregistreerd (e.g. materialenpaspoort, centrale database)	100%

Goals new building, circularity TU Delft (Sustainable vision, 2022)
Part of Appendix C of the Sustainable vision TU Delft

Figure 4 : Total energy use of TU Delft campus buildings in 2018 (Gameren & Van den Dobbelsteen, 2022)



The total energy use of the TU Delft campus buildings monitored in 2018 (Sustainable vision, 2022)
Dark colour indicates educational spaces and offices; light are research functions and labs

Figure 5 : In case study buildings most common steel components, divided into categories used in the report of the European Commission (2002)

EWI collection

Name component	Detail/Section	Retrieved document	Function of component	Additional information	Where to find
Steelprofile IPE 100	Detail 6	Details 36-023-0202	Facade structural support	Connection windowframe to floor	Horizontal profile high rise
Steel anchor rail	Detail 5/6/12	Details 36-023-0202	Facade structural support	Poured into concrete floor, connection floor to facade framework	High rise
Steelprofile IPE 80	Detail 11/12	Details 36-023-0203/4	Facade structural support	Connection windowframe to floor	Horizontal profile high rise
Steelprofile IPE 140	Detail 1/3	Details 36-020-1021	Facade structural support	Edges building outer frame facade	Vertical profile low rise
Steelprofile H 100	Detail 2/33	Details 36-023-0215	Facade structural support	Outer frame facade	Vertical profile high/low rise
Windowframe single glazing b = 40	Detail 11	Details 36-020-1021	Window frames	Glass glued on steel connected to facade support	High rise / low rise
Plaatstalen afdekplaat d =2 mm	Detail 12	Details 36-023-0203	Coverage	Window sill	High rise/Low rise
L-profile	Detail 12	Details 36-023-0203	Heavy structural steel	Connected to ankerrail, under concrete floor	High rise
Corrugated steel cladding	Detail 26	Details 36-023-0206	Profiled cladding or decking	Replacement of a windowframe, in facade framework	High rise
Ventilation duct steel plates d= 1,5 mm	Detail 3a/b,4a/b,5a/b	Details 36-023-0207	Services	Connected to steel windowframes with bolt, dummy & normal ducts	High rise
Steelprofile HE-160-A	Section B-B Corridor	Sections 36-01-01-003	Heavy structural steel	Beam supporting concrete floor	Low rise connecting corridor
Steelprofile HE-200-A	Section B-B Corridor	Sections 36-01-01-003	Heavy structural steel	Beam supporting concrete floor	Low rise connecting corridor
Steelprofile HE-200-A	Section B-B Corridor	Sections 36-01-01-003	Heavy structural steel	Column supporting concrete floor	Low rise connecting corridor
Steel rainwater drainage Ø = 15 cm	Section B-B Corridor	Sections 36-01-01-003	Services	Drainage system of corridor	Low rise connecting corridor
Steelprofile (estimated size) IPE 220	Detail 11, Section B-B High rise	Sections 36-039-0801/Details 36-023-0204	Heavy structural steel	Beam supporting concrete floor, poured in concrete floor	High rise
Steelprofile (estimated size) HE-260 A	Section A-A(?) High rise	Sections 36-039-0800_02	Heavy structural steel	Beam supporting concrete floor, poured in concrete floor	High rise
Steel railing stairs	Section B-B High rise	Sections 36-039-0800_02	Staircases and railings	Railing steel, stairs are concrete, with bolts to concrete	High rise
Trusses (estimated size) h =1 m	Section B-B High rise	Sections 36-039-0800_02	Heavy structural steel	To support the cantilevered roof structure	High rise
Binnenwand: sandwichpanel? d = 40 mm	Detail 7/8/9	Details 36-020-1021	Composite sandwich panels	Interior wall offices	Low rise
Corrugated steel cladding	Site visit	Site visit	Profiled cladding or decking	Covers the 100 m long facade of the low rise hall (with lecture hall C)	Low rise hall 100x50m

TN collection

Name component	Detail/Section	Retrieved document	Function of component	Additional information	Where to find
HE -180-A	Detail 1 (DS-1)	Details 22-AA275880-869	Heavy structural steel	Under IPE 220, bearing roof structure	3rd floor / 4th floor
Steel roof plate d - 0,88, h = 70 mm	Detail 1 (DS-1)	Details 22-AA275880-869	Profiled decking	Roof decking with insulation and bituminous layer	3rd floor / 4th floor
IPE 220	Section Vertical	Details 22-AA275880-884	Heavy structural steel	Bearing roof construction	3rd floor / 4th floor
HE-140-A	Section Vertical	Details 22-AA275880-884	Heavy structural steel	Secundairy construction between IPE 220's	3rd floor / 4th floor
Steel rainwater drainage Ø = 10 cm	Section Vertical	Details 22-AA275880-884	Services	HWA through building, instead of outside	3rd floor / 4th floor
Metal stud wall	Section Vertical/Horizontal	Details 22-AA275880-884	Metal stud wall	As partition walls offices	3rd floor / 4th floor
Steel columns Ø100x100x8 h.o.h. 360	Section Vertical/Horizontal	Details 22-AA275880-884	(Facade) structural support	Partition walls structure	3rd floor / 4th floor
IPE 200	Detail 2	Details 22-AA275880-884	Heavy structural steel	Under facade (loadbearing?)	3rd floor / 4th floor
Steel profiles fake ceiling	Section Vertical	Details 22-AA275880-884	Light gauge steel	Fake ceiling louvre plafond in hallway	3rd floor / 4th floor
Steel tube for pipes	Detail 2	Details 22-AA275880-884	Services	Tube for pipes or electricity cables	3rd floor / 4th floor
Steelplate	Detail 2	Details 22-AA275880-884	Coverage	Coverage of service system (CV)	3rd floor / 4th floor
Four panel steel doorframe	Detail 7	Details 22-AA275909-1733	Doorframes	Steel doorframe connected to exterior steel frame	Ground floor (notch) (pui (NL))
Steel window frames	Detail 1	Details 22-AA275909-1733	Window frames	Steel windowframe connected to exterior steel frame	1st - 4th floor
Profiled cladding	Detail 4	Details 22-AA275909-1733	Profiled cladding	Mostly aesthetically used under steel windowframes	1st - 4th floor
Steelplate super-floor d =150 + 30 mm	Section H,K (master E-42)	Floor plan 22-07-01-068	Composite floor decking system	Profiled steel decking compositely used with reinforced in situ concrete	Ground floor
Reinforcement steel	Detail 10	Floor plan 22-07-01-068	Reinforcement steel bars	Concrete hollow core slab floors with reinforcement steel bars	All floors
Steel window frames	/	Picture site visit	Window frames	All windows are double glazing with steel windowframes	All windows

GS collection

Name component	Detail/Section	Retrieved document	Function of component	Additional information	Where to find
Steel column DIE 12	Longitudinal section	Details 15-12 (6117-N-2)	Heavy structural steel	As columns for the balustrade inside the building	Balustrade inside
Steel beam INP 12	Longitudinal section	Details 15-12 (6117-N-2)	Heavy structural steel	Beams first floor balustrade	Balustrade inside
Steel beam INP 22	Longitudinal section	Details 15-12 (6117-N-2)	Heavy structural steel	Beams first floor balustrade	Balustrade inside
Steel beam INP 24	Longitudinal section	Details 15-12 (6117-N-2)	Heavy structural steel	Beams first floor balustrade	Balustrade inside
Steel beam INP 32	Longitudinal section	Details 15-12 (6117-N-2)	Heavy structural steel	Beams first floor balustrade	Balustrade inside
Railing Ø = 35 mm	View length steel platform	Details 15-12 (6117-N-2)	Stairscases and railings	Railing balustrade first and second floor	Balustrade inside
Stairs (beam UNP 18) b = 90 perforated	Floor plan system B view stairs 442+	Details 15-12 (6117-N-3)	Stairscases and railings	Stairs balustrade	Balustrade inside
Steel glass doors	Floor plan system B	Details 15-12 (6117-N-3)	Doorframes	Four panel steel doorframe	Separation walls inside
Steel column INP 34	Floor plan system B	Details 15-12 (6117-N-3)	Heavy structural steel	Exterior primary construction, connected to interior wall connection	Primary construction exterior
Steel edge profile UNP 14	Floor plan system B	Details 15-12 (6117-N-3)	Heavy structural steel	Interior wall connection to primary construction	Separation walls inside
Steel perforated frames	Vertical section system B	Details 15-12 (6117-N-3)	Staircases and railings	As balustrade flooring	Balustrade inside
Steel profile UNP 18	Vertical section system B	Details 15-12 (6117-N-3)	Heavy structural steel	bearing another UNP 18 on top, bearing balustrade or connected to DIN 14 column in	Balustrade inside
Tread plate d = 6 mm	View length steel platform	Details 15-12 (6117-N-5)	Floor decking system	On top of steel beams, attached with screw bolts	Balustrade inside
Reinforcement steel	Section b-b	Details 15-12 (6117-N-7)	Reinforcement steel	In ground floor and first floor, reinforced concrete	Floors
Steel windowframes	Section b-b	Details 15-12 (6117-N-7)	Windowframes	All windowframes of the exterior, partly interior in partition walls	Exterior
Steel edge profile UNP 26	Section floor iron construction	Details 15-29 (6117-N-19)	Heavy structural steel	Edge profile bearing first floor, on top of DIN 12 column, attached with bolts	Construction inside
Steel beam INP 32	Section floor iron construction	Details 15-29 (6117-N-19)	Heavy structural steel	Bearing first floor, on top of DIN 12 column	Construction inside
Steel beam UNP 12	Floor plan tower	Details 15-39 (6467-E)	Heavy structural steel	Beams bearing floors in tower	Tower construction
Steel beam INP 18	Floor plan tower	Details 15-39 (6467-E)	Heavy structural steel	Bearing steel rasterplates (floors)	Tower construction
Column INP 22	Section C-C tower	Details 15-39 (6467-E)	Heavy structural steel	Poured in concrete	Tower construction
Perforated steel plate raster	Section C-C tower	Details 15-39 (6467-E)	Floor decking system	Used as floor of stairs and balustrade tower	Tower construction

APPENDIX B – ENVIRONMENTAL IMPACT

Figure 1 : Description and activities per phase of LCA steel products (Diagram based on information of the report of the European Commission (2002))

Phase 1	Production of Intermediate Steel Products
Description	Manufacturing of semi-finished steel products such as coils, plates, sections, etc.
Key activities	Raw material extraction, refining, casting, rolling, and initial shaping of steel products.
Phase 2	Production of Finished Steel Construction Products
Description	Transforming intermediate products into finished steel construction materials.
Key activities	Cutting, shaping, coating, and other finishing processes.
Transport	Includes transportation from the steel mill or stockholder to manufacturing facilities.
Phase 3	Construction Phase
Description	On-site and off-site activities involving the assembly, fixing, and erection of steel products for specific applications.
Transport	Includes transportation of steel components to the construction site.
Phase 4	In-Use Phase
Description	Encompasses the entire lifespan of the product within a structure or building.
Key activities	Regular maintenance, repair, and potential replacement of steel components.
Phase 5	End-of-Life Phase
Description	Deals with the demolition, deconstruction, recycling, and final disposal of steel products.
Key activities	Salvage for reuse, recycling, or proper disposal.
Transport	Involves transporting materials from the deconstruction site to recycling or waste treatment facilities.

Figure 2 : Environmental impact per lifecycle phase of common steel components (Diagram based on information of the report of the European Commission (2002))

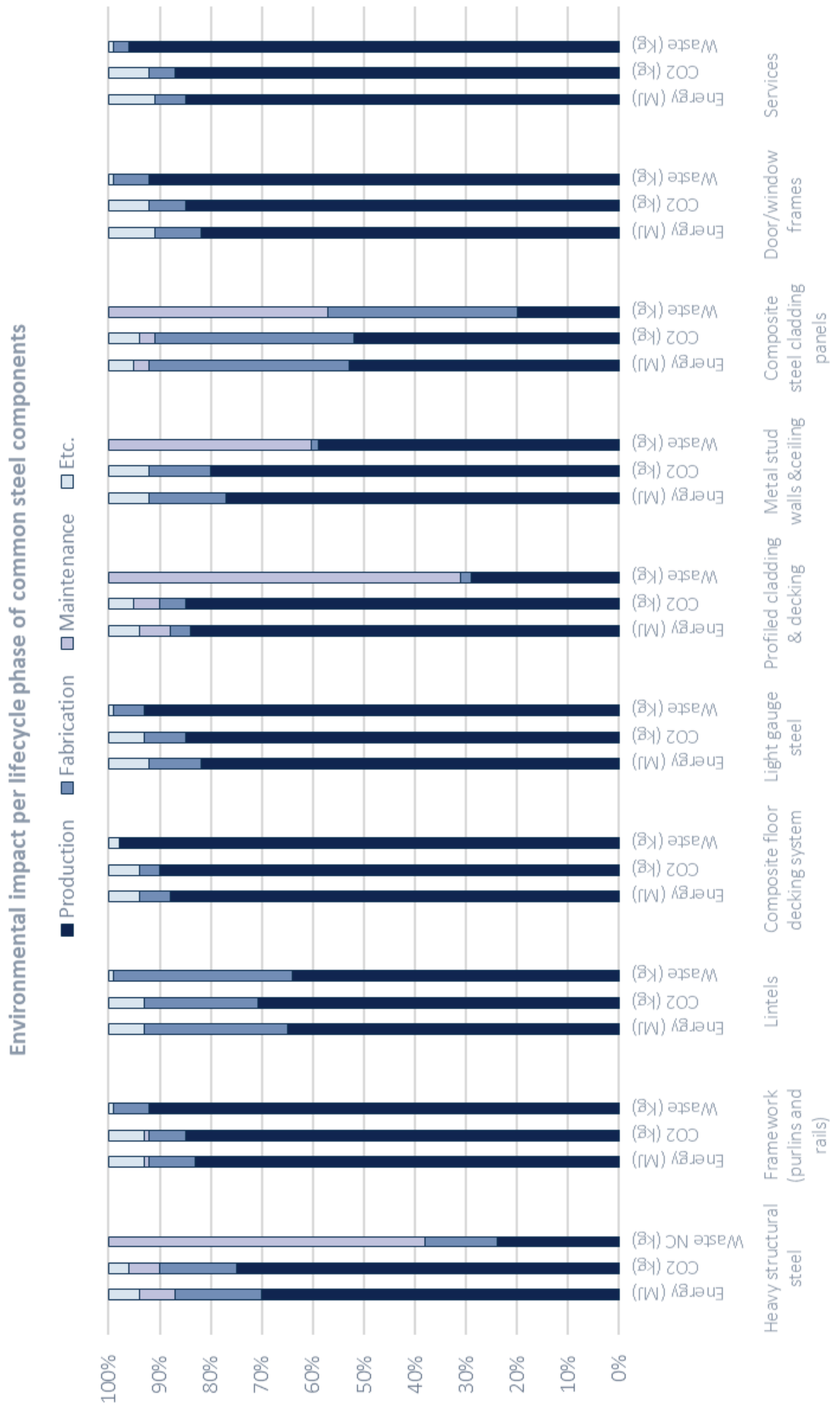


Figure 3 : Overview of a typical steel production process model utilizing **a** recycling and **b** reuse (Haas et al, 2017)

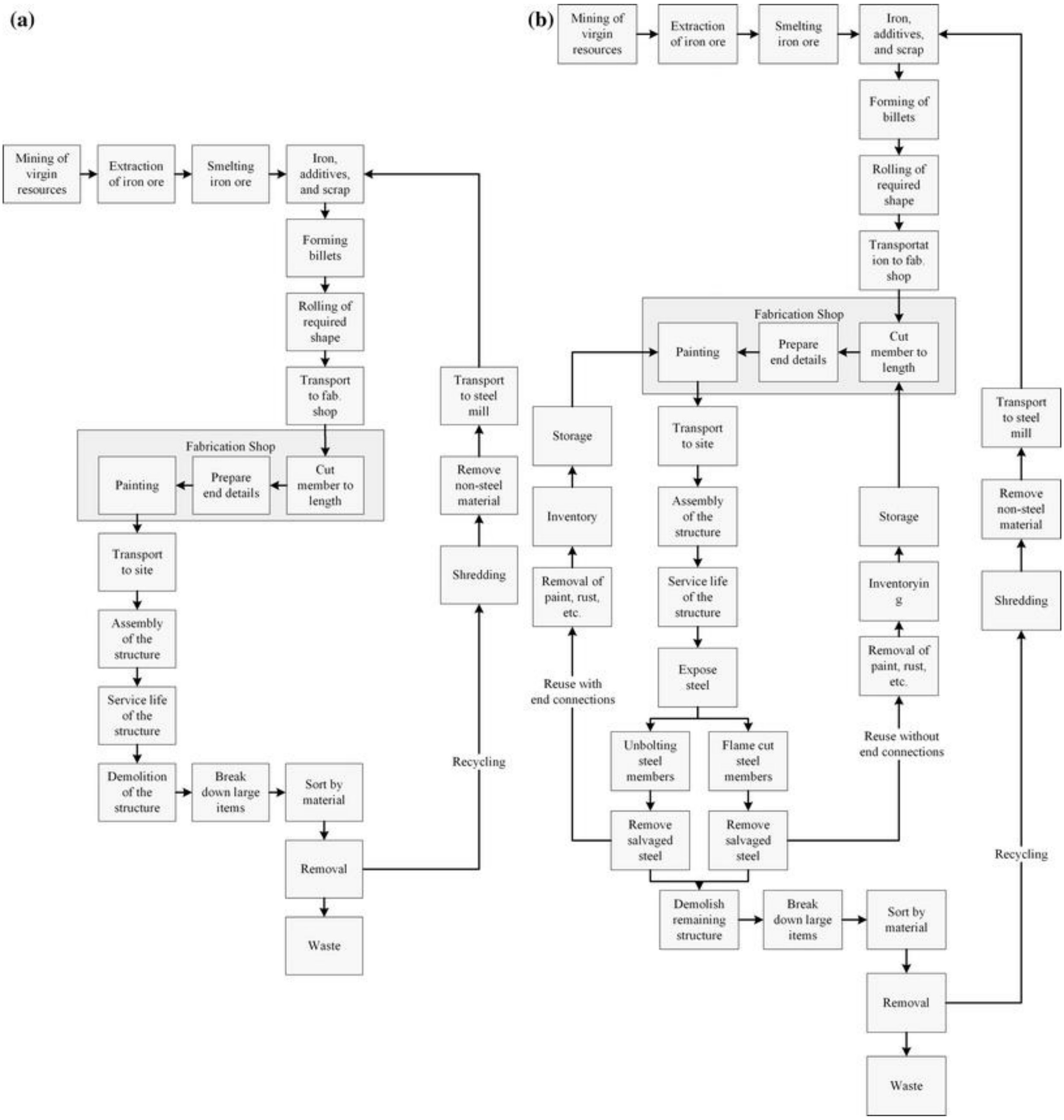


Figure 4 : Sub-processes unique to **a** the recycling process and **b** the reuse process (Haas et al, 2017)

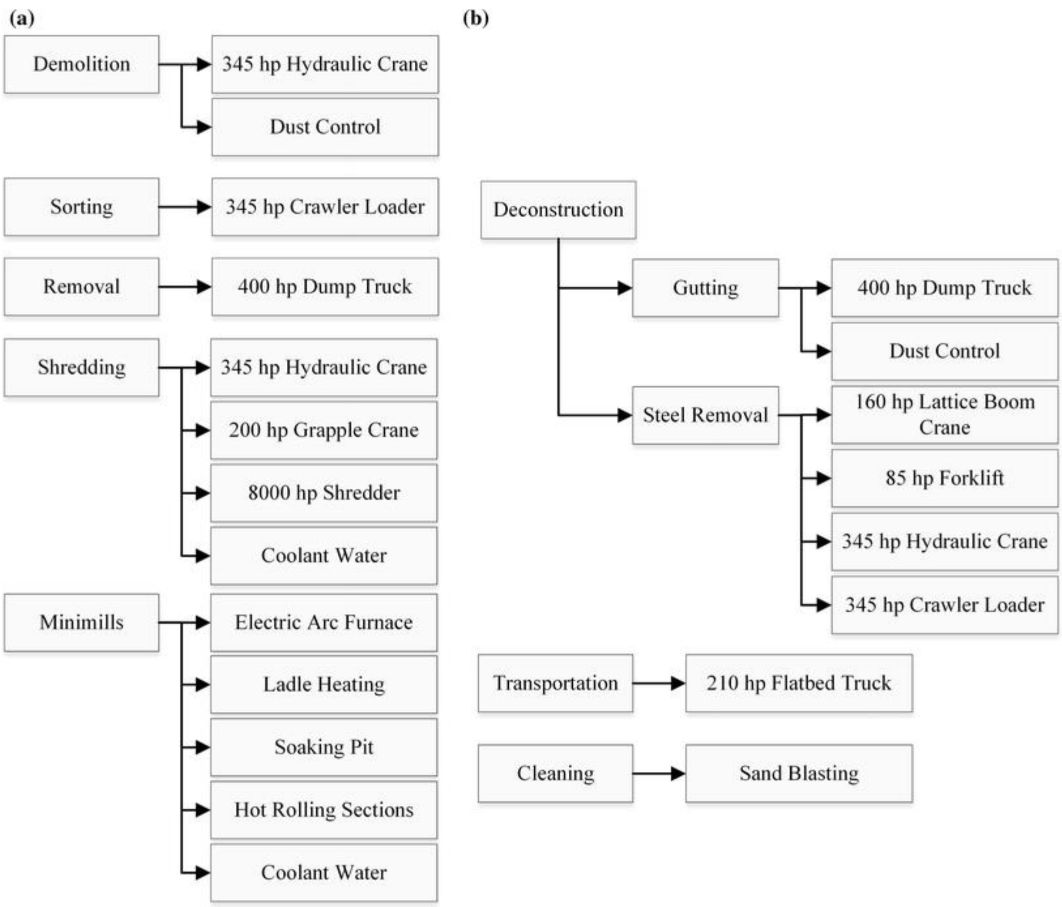


Figure 5 : Emission reduction for steel reuse compared to recycling (Haas et al, 2017)

Metric	Emission reduction (kg/tonne)
CO	0.55
NH_3	-0.30
NO_x	-0.91
PM_{10}	0.07
SO_2	2.30
CO_2	618
CH_4	156
N_2O	2.94
Water (L/tonne)	37,600

Figure 6 : Finished steel products categorized by its intermediate products (European Commission, 2002)

Finished product	IISI intermediate product
Girder	hot dipped galvanised coil (BF)
Lintel	hot rolled coil (BF)
Road barrier	hot rolled coil (BF)
Post coated inner wall components	cold rolled coil (BF)
Doorframes	hot dipped galvanised coil (BF)
Insulated inner wall box	cold rolled coil (BF)
Metalstud wall	hot dipped galvanised coil (BF)
Services	hot dipped galvanised coil (BF)
Light gauge steel (housing)	hot dipped galvanised coil (BF)
Purlins and rails	hot dipped galvanised coil (BF)
Composite floor decking	hot dipped galvanised coil (BF)
Composite sandwich cladding panels	organic coated flat (BF)
Roof plate (coated)	organic coated flat (BF)
Profiled cladding and roofing panels	organic coated flat (BF)
Tapered beam	plate (BF)
Trenchsheeting	hot-rolled coil (BF)
Heavy structural sections	90% sections (BF and EAF) 10% plate (BF)

Figure 7 : EPD production routes and their environmental impact (Duurzaam in Staal, 2004)

Environmental profile for structural steel

Environmental profile for structural steel: data quality = good						
Theme	Unit	Structural steel for heavy-duty applications	Structural steel for medium-duty applications	Structural steel for light-duty applications	Structural steel for interior walls	Structural steel for roof and facade cladding
Toxicity to humans	kg 1.4DB	2.9E+01	4.4E+01	5.1E+01	8.5E+01	3.8E+01
Abiotic exhaustion	kg Sb	2.8E+00	5.5E+00	5.6E+00	6.9E+00	4.4E+00
Ecotoxicity of water (fresh water)	kg 1.4DB	5.7E+00	8.4E+00	1.0E+01	1.6E+01	7.5E+00
Ecotoxicity of sediment (fresh water)	kg 1.4DB	9.2E+00	1.4E+01	1.6E+01	2.7E+01	1.2E+01
Terrestrial ecotoxicity	kg 1.4DB	1.7E-01	2.6E-01	5.9E-01	6.0E-01	2.1E-01
Acidification	kg SO_2	3.0E+00	5.2E+00	5.5E+00	7.3E+00	4.2E+00
Over fertilisation	kg PO_4--	4.2E-01	6.54E-01	7.8E-01	1.1E+00	5.9E-01
Greenhouse effect	kg CO_2	4.8E+02	9.4E+02	9.5E+02	1.2E+03	7.6E+02
Photochemical oxidant formation	kg ethyl	5.1E-01	8.0E-01	1.0E+00	1.4E+00	7.4E-01
Ozone layer depletion	kg CFC11	1.1E-04	1.6E-04	2.0E-04	3.2E-04	1.5E-04

Product group	Production route
Heavy-duty applications	900 kg steel beam (10% BF and 90% EAF) + 100 kg steel plates (BF)
Medium-duty applications	1000 kg hot rolled steel strip (100% BF)
Light-duty applications	1000 kg Sendzimir galvanized steel strip (100% BF)
Internal walls	1000 kg cold rolled steel strip (100% BF)
Roof and facade cladding	1000 kg organically coated steel strip (100% BF)

Figure 8 : EPD of Portland Cement (Cembureau, 2020)

CORE ENVIRONMENTAL IMPACT INDICATORS: 1 tonne Cement CEM I		
		production
Parameter	**Unit**	**A1 - A3**
Global warming potential total (GWP total)	kg CO_2 eq.	803
Global warming potential fossil (GWP fossil)	kg CO_2 eq.	803[*1)]
Global warming potential biogenic (GWP biogenic)	kg CO_2 eq.	0.22[*2)]
Depletion potential of the stratospheric ozone layer (ODP)	kg CFC 11 eq.	1.8E-7
Acidification potential, accumulated exceedance (AP)	mol H+ eq.	1.82
Eutrophication potential, fraction of nutrients reaching freshwater end compartment (EP-freshwater)	kg PO_4 eq.	0.000324
Eutrophication potential, fraction of nutrients reaching marine end compartment (EP-marine)	kg N eq.	0.51
Eutrophication potential, accumulated exceedance (EP-terrestrial)	mol N eq.	6.01
Formation potential of tropospheric ozone (POCP)	kg NMVOC eq.	2.33
Abiotic depletion potential for non-fossil resources (ADP-minerals and metals)	kg Sb eq.	1.82E-5[*3)]
Abiotic depletion potential for fossil resources (ADP-fossil fuels)	MJ, net calorific value	3130[*3)]
Water (user) deprivation potential, deprivation weighted water consumption	m^3 world eq. deprived	14.1[*3)]

APPENDIX C – COSTS

Figure 1 : Overview of possible test methods that needs to be conducted for reuse of a steel element, divided into the three most expensive test categories (constructive safety, fire safety, wind load calculations)

Constructieve veiligheid testen staal element	
Inspecties:	Aanvullende informatie
Materiaalinspecties:	
Chemische Samenstellingstest (NDT)	Spectometrie, XRF, Oxidatiereductiemethode
Mechanische Eigenschappentest (DT)	Trekproeven en slagproeven
Ultrasone testen (NDT)	Voor interne gebreken of discontinuïteiten
Hardheidstesten (NDT)	Sterkte en slijtvastheid, methodes: Brinell, Vickers en Rockwell
Lasinspecties:	
Visuele inspectie	Scheuren, porositeit, slakinsluitingen, onvolledige fusie
Penetrant Testing	Oppervlaktefouten in niet-poreuze materialen te detecteren
Magnetic Particle Testing	Oppervlaktefouten detecteren in ferromagenetische materialen
Radiographic Testing	Interne gebreken in de las detecteren
Ultrasonic Testing	Interne gebreken in de las detecteren
X-ray Computed Tomography	Driedimensionale beelden van lasverbindingen
Conservering inspecties:	
Visuele inspectie	Blazen, barsten, krassen of andere gebreken in de coating
Diktemeting (Magnetische industie meting)	Vereiste laagdikte weten want essentieel voor effectieve corrosiebescherming
Hechtingstest	Hechting van coating aan oppervlak via insnijden ruitpatroon
Zout sproei test	Beoordeeld weerstand van de coating tegen corrosie

Brandveiligheid testen staal element	
Inspecties:	Aanvullende informatie
Coating staal inspecties:	
Visuele inspectie	Blazen, barsten, krassen of andere gebreken in de coating
Diktemeting (Ultrasone meting)	Vereiste laagdikte meten want dikte essentieel voor brandwerendheid
Adhesietest	Hechting van coating aan oppervlak via insnijden ruitpatroon
Cohesietest	Beoordeeld interne sterkte van de coating
Zout sproei test	Beoordeeld weerstand van de coating tegen corrosie
Hardheidstest	Meet weerstand van de coating tegen indrukking of penetratie
Blootstellen monster aan vuur	Vuurverspreiding, rookontwikkeling en productie van giftige gassen

Windbelasting testen staal element	
Inspecties:	Aanvullende informatie
Materiaalinspecties:	
Chemische Samenstellingstest (NDT)	Spectometrie, XRF, Oxidatiereductiemethode
Mechanische Eigenschappentest (DT)	Trekproeven en slagproeven
Ultrasone testen (NDT)	Voor interne gebreken of discontinuïteiten
Hardheidstesten (NDT)	Sterkte en slijtvastheid, methodes: Brinell, Vickers en Rockwell
Lasinspecties:	
Visuele inspectie	Scheuren, porositeit, slakinsluitingen, onvolledige fusie
Penetrant Testing	Oppervlaktefouten in niet-poreuze materialen te detecteren
Magnetic Particle Testing	Oppervlaktefouten detecteren in ferromagenetische materialen
Radiographic Testing	Interne gebreken in de las detecteren
Ultrasonic Testing	Interne gebreken in de las detecteren
X-ray Computed Tomography	Driedimensionale beelden van lasverbindingen
Inspectie windbelasting element op nieuwe locatie:	
Computermodel windbelasting	Simulatie van de windbelasting op het element
Structuur technische analyse	Beoordeling welke versterking nodig is bij element middels computersoftware
Prototyping	Testen van prototype van element door deze op locatie te plaatsen

APPENDIX D – LONGEVITY

Figure 1 : Seven principles of connections ranged from fixed to flexible connections (Durmirsevic, 2006)

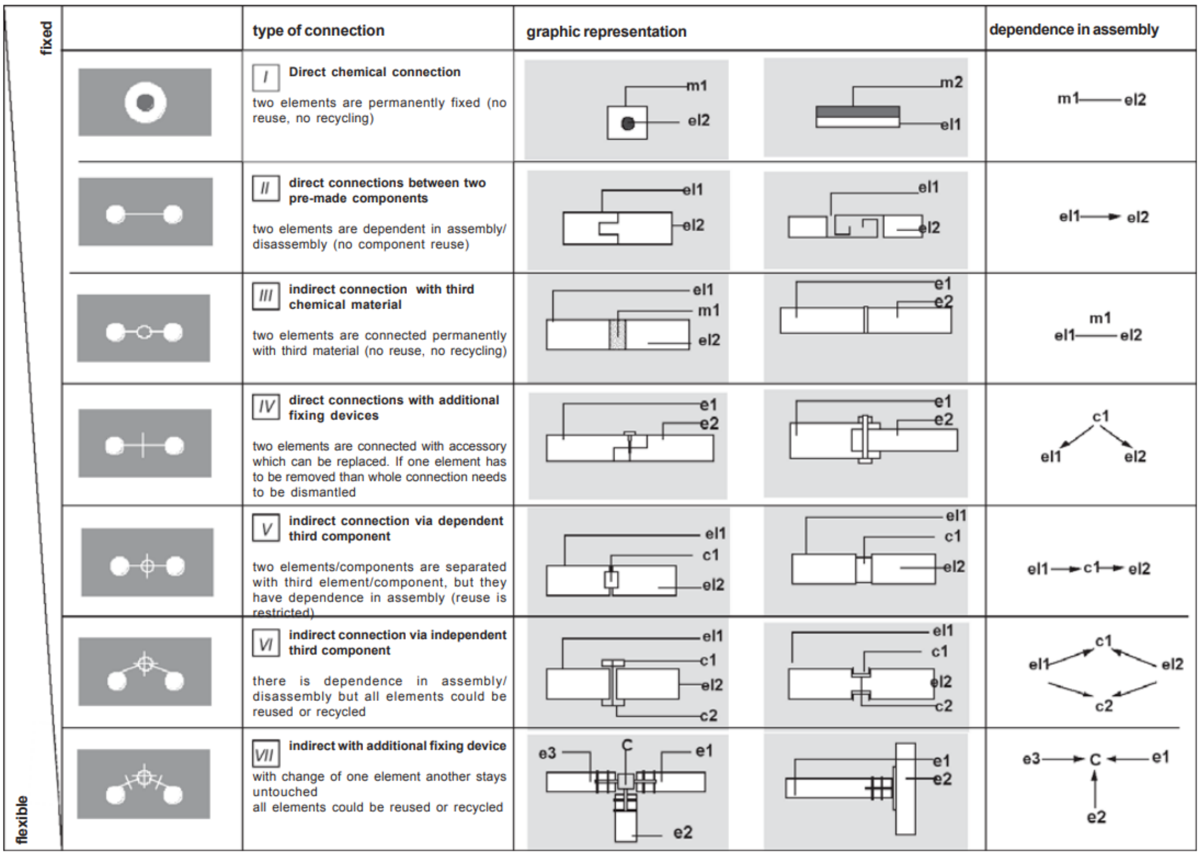
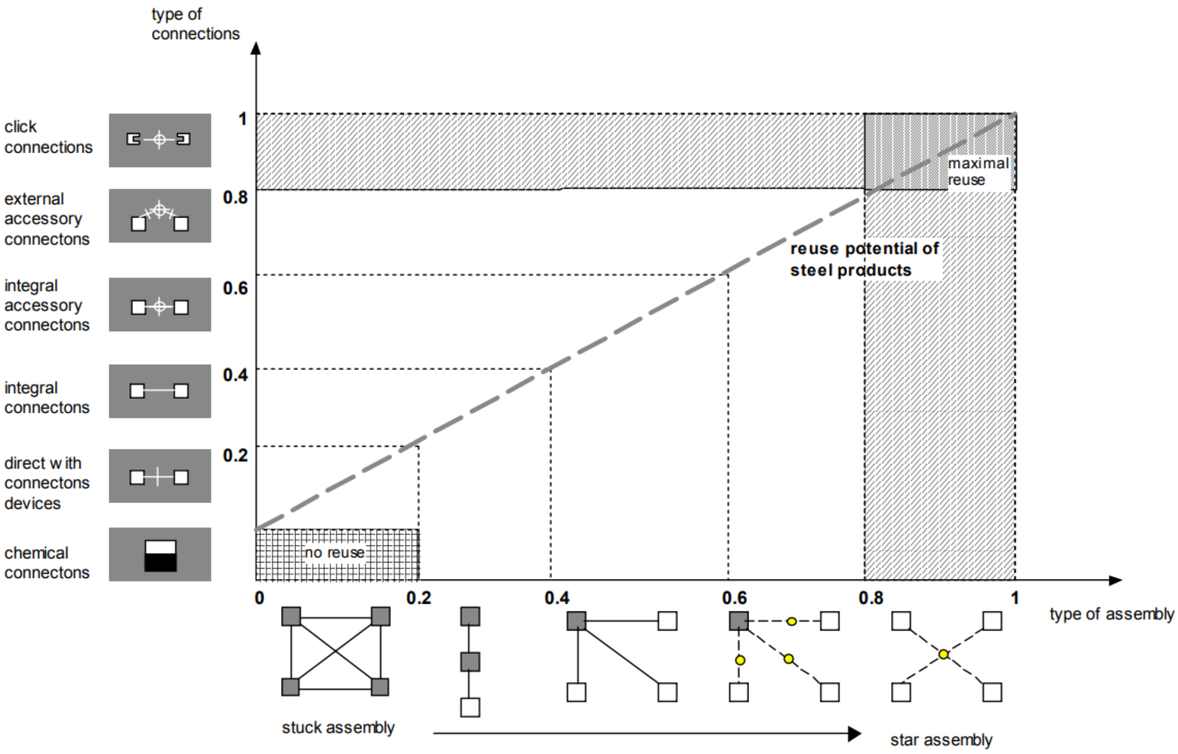


Figure 2 : Reuse potential of steel products depending on type of connection and assembly (Durmirsevic, 2006)



APPENDIX E – VALUE ASSESSMENT

Figure 1 : Elaborated version value assessment of steel components EWI

Value assessment steel product groups EWI	Environment		Costs					Longevity						
	Volumetric impact	Environ-mental impact	Procurement	Inspections	Ease of dismantling	Storage	Transport	Demountability	Performance	Condition	Defects	Coating	Aesthetic value
Heavy Structural Steel	High (220 m3)	Steel EPD medium, 500 kg CO2/tonne	Supply and takeover by same entities	Expensive: structural safety, fire safety and wind load requirements inspections	Due to stuck assembly not easily demountable and in need of heavy machinery to effectively remove from building	TU Delft storage	Local harvesting within radius of 5 kilometres, compact transport	Indirect chemical connection, stuck assembly (partly poured in concrete)	x	No rust visible on columns, beams poured in concrete not visible	x	Heavy structural steel often hot dip galvanized, which is a long lasting coating and still in great condition	Structural steel mostly not visible, otherwise well taken care of with great coating
Structural framework	High (48 m3)	Steel EPD medium, 500 kg CO2/tonne	Supply and takeover by same entities	Expensive: structural safety, fire safety and wind load requirements inspections	Easily demountable, however in need of heavy machinery to effectively remove from building	TU Delft storage	Local harvesting within radius of 5 kilometres, compact transport	Indirect external connection with additional fixing devices via independent connection device, open assembly	x	No rust visible	x	Structural framework often hot dip galvanized, which is a long lasting coating, medium great condition	Light reflective grey coating, however with slight wear and tear visible
Lintels	/	/	/	/	/	/	/	/	/	/	/	/	/
Reinforcement steel bars	Low (6,3 m3)	Steel EPD medium, 500 kg CO2/tonne	Supply and takeover by same entities	Expensive: structural safety	Due to stuck assembly not easily demountable and in need of heavy machinery to effectively remove from building	TU Delft storage	Local harvesting within radius of 5 kilometres, compact transport	Indirect chemical connection, stuck assembly (poured in concrete)	x	Probably rusty but not visible	x	Probably not coated due to protection from surrounding concrete	Not visible
Composite floor decking system	/	/	/	/	/	/	/	/	/	/	/	/	/
Light Gauge Steel	Low (4 m3)	Steel EPD high, 950 kg CO2/tonne	Supply and takeover by same entities	Medium expensive: fire safety and wind load	Easily demountable and not in need of heavy machinery	TU Delft storage	Local harvesting within radius of 5 kilometres, compact transport	Indirect external connection via independent connection device, open assembly	x	No rust visible	x	Often hot dip galvanized or powder coating, still in great condition	Galvanized look makes the steel surface looking smooth
Profiled cladding or decking	Low (2,2 m3)	Steel EPD medium, 750 kg CO2/tonne	Supply and takeover by same entities	Medium expensive: fire safety, wind load and waterproofing	Easily demountable and due to application in the low rise parts not in need of heavy machinery to dismantle	TU Delft storage	Local harvesting within radius of 5 kilometres, medium compact transport	Indirect external connection with additional fixing devices via independent connection device, open assembly	x	Medium amount of rust visible	x	Paint coating based on expoxy and polyurethaan, not long lasting, not in great condition	Medium aesthetic, profiled cladding with slight amount of rust
Metal Studs walls or ceiling	Low (9,0 m3)	Steel EPD high, 950 kg CO2/tonne	Supply and takeover by same entities	Medium expensive: fire safety	Not easily demountable, has to be sawn one by one and therefore time consuming	TU Delft storage	Local harvesting within radius of 5 kilometres, medium compact transport	Direct snap fit connection & direct connections with additional fixing devices, layered assembly	x	Not visible	x	Often hot dip galvanized, still in great condition	Not visible
Composite sandwich panels	Medium (10 m3)	Steel EPD medium, 750 kg CO2/tonne	Supply and takeover by same entities	Medium expensive: fire safety, wind load and waterproofing, thermal and sound insulation	Easily demountable and not in need of heavy machinery due to application in the low rise parts	TU Delft storage	Local harvesting within radius of 5 kilometres, medium compact transport	Indirect external connection via independent connection device, open assembly	x	No rust visible	x	Sandwhich elements often powder coated based on paint with PVDF, still in great condition	In great condition, with grey finish, no rust
Doorframes	Low (3 m3)	Steel EPD high, 950 kg CO2/tonne	Supply and takeover by same entities	Not expensive: waterproofing/thermal insulation for exterior doors, dimensial specifications	Easily demountable not in need of heavy machinery	TU Delft storage	Local harvesting within radius of 5 kilometres, medium compact transport	Indirect external connection with additional fixing devices to independent connection device, layered assembly	x	No rust visible	x	Paint coating based on expoxy and polyurethaan, not long lasting, however due to interior application still in medium condition	Doors with slight wear and tear, colour of coating subjectively not pleasant to the eye
Windowframes	High (34 m3)	Steel EPD high, 950 kg CO2/tonne	Supply and takeover by same entities	Not expensive: waterproofing/thermal/ sound insulation	Frame not demountable, with heavy machinery frame and glass can be removed from building	TU Delft storage	Local harvesting within radius of 5 kilometres, medium compact transport	Direct connection with additional fixing device, stuck assembly	x	Slight amount of rust on exterior window frames	x	Windowframes in 1960-70's often powder coated, not long lasting, in medium condition	The sealant is all over the glasses and the windowframe, frame shows slight wear and tear
Staircases and railings	Low (5,2 m3)	Steel EPD medium, 750 kg CO2/tonne	Supply and takeover by same entities	Expensive: structural safety and fire safety	Easily demountableand need for heavy machinery depending on where it is applicated	TU Delft storage	Local harvesting within radius of 5 kilometres, medium compact transport	Just a few railings concrete stairs; direct chemical connection (railing poured in concrete) stuck assembly, other parts are indirect external connections	x	Exterior stairs slight amount of rust, interior stairs no rust visible	x	Exterior stairs often hot dip galvanized, powder coating used for interior stairs, varies between great/ not great condition	Interior railings looking like they are new, exterior stairs have a functional look, not specifically aesthetic
Services	High (60 m3)	Steel EPD high, 950 kg CO2/tonne	Supply and takeover by same entities	Medium expensive: waterproofing and wind laod	Easily demountable and not in need of heavy machinery for interior air ducts, grilles in facade need heavy machinery to remove it from the building	TU Delft storage	Local harvesting within radius of 5 kilometres, Low compact transport	Indirect external connection with additional fixing devices via independent connection device, open assembly, however depending on type of service element	x	Medium to high amount of rust on ventilation grilles in facade, other services perfect condition	x	No coating: stainless steel	Grilles facade show wear and tear, but ventilation ducts have a smooth finish due to galvanization

Figure 2 : Elaborated version value assessment of steel components TN

Value assessment steel product groups TN	Environment		Costs					Longevity					
	Volumetric impact	Environmental impact	Procurement	Inspections	Ease of dismantling	Storage	Transport	Demountability	Performance	Condition	Defects	Coating	Aesthetic value
Heavy Structural Steel	50 m3	Steel EPD medium, 500 kg CO2/tonne	Supply and takeover by same entities	Expensive: structural safety, fire safety and wind load requirements inspections	Steel in superstructure easily demountable due to parallel assembly, other steel stuck assembly, poured in concrete	TU Delft storage	Local harvesting within radius of 5 kilometres, compact transport	Indirect chemical connection, stuck assembly (partly poured in concrete), in superstructure parralel assembly with external connection devices: demountable	x	Columns and beams superstructure in great condition, poured in concrete steel not visible	x	Heavy structural steel often hot dip galvanized, which is a long lasting coating and still in great condition	Structural steel mostly not visible, otherwise well taken care of with great coating
Structural framework	5,2 m3	Steel EPD medium, 500 kg CO2/tonne	Supply and takeover by same entities	Expensive: structural safety, fire safety and wind load requirements inspections	Easily demountable, however in need of heavy machinery to effectively remove from the building	TU Delft storage	Local harvesting within radius of 5 kilometres, compact transport	Indirect external connection with additional fixing devices via independent connection device, open assembly	x	No rust visible	x	Structural framework often hot dip galvanized, which is a long lasting coating, medium great condition	Light reflective grey coating, however with slight wear and tear visible
Lintels	/	/	/	/	/	/	/	/	/	/	/	/	/
Reinforcement steel bars	5,2 m3	Steel EPD medium, 500 kg CO2/tonne	Supply and takeover by same entities	Expensive: structural safety	Due to stuck assembly not easily demountable and in need of heavy machinery to effectively remove from building	TU Delft storage	Local harvesting within radius of 5 kilometres, compact transport	Indirect chemical connection, stuck assembly (poured in concrete)	x	Probably rusty but not visible	x	Probably not coated due to protection from surrounding concrete	Not visible
Composite floor decking system	40 m3	Steel EPD high, 950 kg CO2/tonne	Supply and takeover by same entities	Expensive: structural safety	Due to stuck assembly not easy to dismantle. To remove the concrete slabs from the steel is labour intensive and needs heavy machinery	TU Delft storage	Local harvesting within radius of 5 kilometres, compact transport	Direct chemical connection (removing concrete slabs severely damages steel), parallel assembly	x	Not visible, however galvanized so probably not rusty	x	Often hot dip galvanized or powder coating, still in great condition	Not visible
Light Gauge Steel	1,7 m3	Steel EPD high, 950 kg CO2/tonne	Supply and takeover by same entities	Medium expensive: fire safety and wind load	Easily demountable and not in need of heavy machinery	TU Delft storage	Local harvesting within radius of 5 kilometres, compact transport	Indirect external connection via independent connection device, open assembly	x	No rust visible	x	Often hot dip galvanized or powder coating, still in great condition	Galvanized look makes the steel surface looking smooth
Profiled cladding or decking	22 m3	Steel EPD medium, 750 kg CO2/tonne	Supply and takeover by same entities	Medium expensive: fire safety, wind load and waterproofing	Easily demountable due to parallel assembly, no heavy machinery. Profiled decking in roof also easy to dismantle.	TU Delft storage	Local harvesting within radius of 5 kilometres, medium compact transport	Indirect external connection with additional fixing devices via independent connection device, open assembly	x	No rust visible on superstructure decking, slight amount of rust on exterior cladding under windowframes	x	Paint coating based on expoxy and polyurethaan, still in great condition	Cladding under windowframes with dark blue coating, no wear and tear visible
Metal Studs walls or ceiling	7,7 m3	Steel EPD high, 950 kg CO2/tonne	Supply and takeover by same entities	Medium expensive: fire safety	Not easily demountable, has to be sawn one by one and therefore time consuming	TU Delft storage	Local harvesting within radius of 5 kilometres, medium compact transport	Direct snap fit connection & direct connections with additional fixing devices, layered assembly	x	No rust visible	x	Often hot dip galvanized, still in great condition	Not visible
Composite sandwich panels	/	/	/	/	/	/	/	/	/	/	/	/	/
Doorframes	2,2 m3	Steel EPD high, 950 kg CO2/tonne	Supply and takeover by same entities	Not expensive: waterproofing/thermal insulation for exterior doors, dimensial specifications	Easily demountable not in need of heavy machinery	TU Delft storage	Local harvesting within radius of 5 kilometres, medium compact transport	Indirect external connection with additional fixing devices to independent connection device, layered assembly	x	No rust visible	x	Paint coating based on expoxy and polyurethaan, not long lasting, however still in great condition	Exterior and interiors door have a great grey/dark blue coating, no wear and tear visible
Windowframes	11,0 m3	Steel EPD high, 950 kg CO2/tonne	Supply and takeover by same entities	Not expensive: waterproofing/thermal/ sound insulation	Frame not demountable from glass but if dismantled together, easily demountable	TU Delft storage	Local harvesting within radius of 5 kilometres, medium compact transport	Direct connection with additional fixing device, stuck assembly	x	Slight amount of rust on exterior window frames, superstructure no rust visible	x	Windowframes in 1960-70's often powder coated, not long lasting, in medium condition	Frames of superstructure looking like they are new, however plastic look. Other windowframes show some slight wear and tear
Staircases and railings	2,5 m3	Steel EPD medium, 750 kg CO2/tonne	Supply and takeover by same entities	Expensive: structural safety and fire safety	Easily demountable, emergency staircases not in need of heavy machinery to remove from building	TU Delft storage	Local harvesting within radius of 5 kilometres, medium compact transport	Just a few railings concrete stairs; direct chemical connection (railing poured in concrete) stuck assembly, emergency stairs have indirect external connections	x	Exterior stairs slight amount of rust, interior stairs no rust visible	x	Exterior stairs often hot dip galvanized, powder coating used for interior stairs, varies between great/ not great condition	Interior railing with great finishing, exterior stairs have a functional look, not specifically aesthetic
Services	14 m3	Steel EPD high, 950 kg CO2/tonne	Supply and takeover by same entities	Medium expensive: waterproofing and wind laod	Easily demountable and not in need of heavy machinery	TU Delft storage	Local harvesting within radius of 5 kilometres, Low compact transport	Indirect external connection with additional fixing devices via independent connection device, open assembly, however depending on type of service element	x	No rust visible, stainless steel used for services	x	No coating: stainless steel	Stainless steel makes the steel surface looking smooth with no wear and tear

Figure 3 : Elaborated version value assessment of steel components GS

Value assessment steel product groups GS	Environment		Costs					Longevity						
	Volumetric impact	Environmental impact	Procurement	Inspections	Ease of dismantling	Storage	Transport	Demountability	Performance	Condition	Defects	Coating	Aesthetic value
Heavy Structural Steel	10,2 m3	Steel EPD medium, 500 kg CO2/tonne	Supply and takeover by same entities	Expensive: structural safety, fire safety and wind load requirements inspections	Some heavy steel columns are stuck inbetween brick layers and mostly welded, so less easy to dismantle, beams easier to dismantle.	TU Delft storage	Local harvesting within radius of 5 kilometres, compact transport	Indirect chemical connection, stuck assembly (inbetween brickwork)	x	Columns and beams medium amount of rust (beams exposed to weather, visible on exterior facade)	x	Rusty condition, coating not working good anymore	The beams were black coated, however due to the rust it now is black and orange coloured. Industrial look
Structural framework	/	/	/	/	/	/	/	/	/	/	/	/	/
Lintels	4,2 m3	Steel EPD high, 950 kg CO2/tonne	Supply and takeover by same entities	Expensive: structural safety, fire safety and wind load requirements inspections	Not easily demountable, bricks have to be removed carefully and this is time consuming	TU Delft storage	Local harvesting within radius of 5 kilometres, compact transport	Welded to structure, chemical cnnection	X	Only some edges visible in facade, these have a medium amount of rust	X	Probably the paint coating is chipped, however not clearly visible	Rusty coloured steel, looking old and used
Reinforcement steel bars	/	/	/	/	/	/	/	/	/	/	/	/	/
Composite floor decking system	/	/	/	/	/	/	/	/	/	/	/	/	/
Light Gauge Steel	1,7 m3	Steel EPD high, 950 kg CO2/tonne	Supply and takeover by same entities	Medium expensive: fire safety and wind load	Easily demountable and not in need of heavy machinery	TU Delft storage	Local harvesting within radius of 5 kilometres, compact transport	Indirect external connection via independent connection device, open assembly	x	Slight amount of rust visible	x	Galvanized, however not in the best condition after all these years	Looking at some place like it is burned because of the specific places of rust
Profiled cladding or decking	2,4 m3	Steel EPD medium, 750 kg CO2/tonne	Supply and takeover by same entities	Medium expensive: fire safety, wind load and waterproofing	Easily demountable due to parallel assembly, no heavy machinery.	TU Delft storage	Local harvesting within radius of 5 kilometres, medium compact transport	Indirect external connection with additional fixing devices via independent connection device, open assembly	x	Medium to high amount of rust on exterior cladding	x	Paint coating based on expoxy and polyurethaan, chipped	Wear and tear visible, however, might be considered as 'industrial look'
Metal Studs walls or ceiling	1,1 m3	Steel EPD high, 950 kg CO2/tonne	Supply and takeover by same entities	Medium expensive: fire safety	Not easily demountable, has to be sawn one by one and therefore time consuming.	TU Delft storage	Local harvesting within radius of 5 kilometres, medium compact transport	Direct snap fit connection & direct connections with additional fixing devices, layered assembly	x	Slight amount of rust visible	x	Galvanized, however not in the best condition after all these years	Looking at some place like it is burned because of the specific places of rust
Composite sandwich panels	/	/	/	/	/	/	/	/	/	/	/	/	/
Doorframes	2,1 m3	Steel EPD high, 950 kg CO2/tonne	Supply and takeover by same entities	Not expensive: waterproofing/thermal insulation for exterior doors, dimensial specifications	Easily demountable not in need of heavy machinery	TU Delft storage	Local harvesting within radius of 5 kilometres, medium compact transport	Indirect external connection with additional fixing devices to independent connection device, layered assembly	x	Slight amount of rust visibe	x	Paint coating based on expoxy and polyurethaan, not in great condition, chipped	The composition of the glasswork and steel doors has a characteristic, historical, industrial look
Windowframes	2,8 m3	Steel EPD high, 950 kg CO2/tonne	Supply and takeover by same entities	Not expensive: waterproofing/thermal/ sound insulation	Frame not demountable from glass but if dismantled together, easily demountable. Some parts welded to balustrade or stairs, these are harder to dismantle	TU Delft storage	Local harvesting within radius of 5 kilometres, medium compact transport	Indirect external connection with dependent fixing device (facades) Some chemical connections, near the balustrade.	x	Slight amount of rust on exterior window frames, superstructure no rust visible	x	Windowframes powder coated, not long lasting, medium condition. Glass fell out of frames on exterior facade	The composition of the glasswork and steel doors has a characteristic, historical, industrial look
Staircases and railings	3,1 m3	Steel EPD medium, 750 kg CO2/tonne	Supply and takeover by same entities	Expensive: structural safety and fire safety	Varying from easily, to not easily demountable. It depends upon where the component is situated.	TU Delft storage	Local harvesting within radius of 5 kilometres, medium compact transport	Direct chemical connections and stuck assembly, to external connections and parallel assembly, depending on where it is situated. Most parts of balustrade and stairs tower; external connections.	x	Balustrade with slight amount of rust visible	x	Galvanized, however showing some slight amount of rust	Looking at some place like it is burned because of the specific places of rust, industrial look
Services	2,1 m3	Steel EPD high, 950 kg CO2/tonne	Supply and takeover by same entities	Medium expensive: waterproofing and wind laod	Easily demountable and not in need of heavy machinery	TU Delft storage	Local harvesting within radius of 5 kilometres, Low compact transport	Indirect external connection with additional fixing devices via independent connection device, open assembly, however depending on type of service element	x	Medium amount of rust visible	x	/	Service systems show some wear and tear, do not look clean

Figure 4 : Decision chart fixed and flexible factors