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ERASMUS MUNDUS JOINT MASTER DEGREE

**MASTER DEGREE IN SUSTAINABLE DESIGN, CONSTRUCTION
AND MANAGEMENT OF THE BUILT ENVIRONMENT**

MBUILD

Re-use of Steel- Advantages of and existing constraints for the use of re-used steel products

MATHIYAS THATAL

Supervision:

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Co-Supervisor: Dr.-Ing. Manuel Koob (THM)

Giessen, July 2024



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Dedicated to
My Beloved Family

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ABSTRACT

The construction industry significantly contributes to global energy consumption and greenhouse gas emissions, largely due to the production of building materials. To mitigate this environmental impact, this master's thesis investigates the potential for increasing the reuse of steel products within the civil engineering sector, aiming to enhance sustainability. The research is structured into several key phases. Initially, extensive literature studies are conducted to summarize the current state of steel reuse, providing an overview of reuse rates in various countries and the factors that either promote or hinder the reuse of steel in construction. The following phase involves analyzing the collected information to identify the key challenges that hold up the use of reclaimed materials in construction. This analysis helps identify specific constraints and provides a foundation for further research aimed at resolving these issues, ultimately increasing the reuse rate of steel products globally. The final phase of the research focuses on developing a strategic proposal. This proposal outlines how government policies and the civil engineering community can modify existing conditions to enhance the reuse rate of steel products.

The goal is to identify solutions that significantly increase the reuse of steel materials, considering the numerous benefits of such practices, which will improve the sustainable use of steel and reduce the environmental impact of the construction industry. By addressing these conditions, the research aims to contribute to the broader objective of promoting sustainable construction practices and reducing greenhouse gas emissions. This thesis highlights the importance of regulatory frameworks in guiding sustainable practices and emphasizes the need for similar regulations globally. Moreover, it contributes a comprehensive study that provides new researchers with an overview of this topic, including guidance on how to start, what to focus on, and what steps are needed.

Keywords: Re-use of steel products, increase of sustainability, existing constraints, advantages of re-use

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SYMBOLS, ACRONYMS AND ABBREVIATIONS

EU	-	European Union
EF	-	Electric Furnace
BOF	-	Basic Oxygen Furnace
GWP	-	Global Warming Potential
ECSC	-	European Coal and Steel Community
SCI	-	Steel Construction Institute
NFDC	-	National Federation of Demolition Contractors
LCA	-	Life Cycle Assessment
LCC	-	Life Cycle Cost
PROGRESS	-	Provisions for a Greater Reuse of Steel Structures
NTS	-	National Tube Stockholders
BIM	-	Building Information Modeling
DB	-	Data Base
Ref	-	Reference
Fig	-	Figure

1

INTRODUCTION

1.1. BACKGROUND TO THE STUDY

In recent years, the necessity of sustainability has persuaded a critical re-evaluation of resource utilization practices across various industries. Within the domain of civil engineering, the construction sector stands as a significant consumer of resources, with steel playing a pivotal role in structural frameworks and infrastructure development. However, traditional construction practices often result in a linear model of material consumption, characterized by extraction, fabrication, utilization, and disposal, contributing to environmental degradation and resource depletion. In response to these challenges, there has been a growing recognition of the need to transition towards more circular and sustainable approaches to material usage, with an emphasis on maximizing resource efficiency and minimizing waste generation. Against this constraint, the reuse of steel products emerges as a compelling strategy for enhancing the sustainability of construction practices, offering the potential to reduce environmental impact, conserve resources, and mitigate carbon emissions.

1.2. STATEMENT OF RESEARCH PROBLEM

Despite the potential benefits associated with the reuse of steel, significant barriers and constraints persist, hindering widespread adoption within the civil engineering sector. Key questions arise regarding the factors influencing the reutilization rates of steel products, the efficacy of existing regulatory frameworks and incentives, and the potential strategies for overcoming barriers to adoption. This thesis seeks to address these pressing questions by investigating the advantages and constraints of steel reuse and proposing actionable strategies for enhancing reutilization rates within a civil engineering framework.

1.3. PURPOSE OF THE STUDY

The primary aim of this research is to formulate proposals aimed at increasing the reuse rate of steel products within the civil engineering and construction community. To achieve this principal aim, the following objectives will be pursued:

- Conduct an extensive literature review to synthesize existing knowledge on the reuse of steel products and identify key trends, challenges, and opportunities.
- Analyze reutilization rates across different countries to observe patterns and factors influencing adoption.

- Identify barriers and constraints hindering the widespread adoption of steel reuse within different countries.
- Develop recommendations for governmental bodies and civil engineering communities to enhance the reutilization of steel products and promote sustainable material usage practices.

1.4. SCOPE AND LIMITATIONS

This research focuses specifically on the reuse of steel products within the civil engineering sector, with an emphasis on identifying strategies for increasing reutilization rates. While the study acknowledges the broader global context of steel reuse, the scope will be delimited to the chosen country to facilitate a more targeted analysis and formulation of proposals. It is important to note that this research does not aim to provide a comprehensive assessment of all factors influencing steel reuse but rather to offer strategic insights and recommendations for enhancing reutilization rates within a specific context.

1.5. SIGNIFICANCE AND CONTRIBUTION

This research is significant in that it addresses a pressing environmental and economic challenge facing the civil engineering sector, namely, the need to transition towards more sustainable material usage practices. By clarifying the advantages and constraints of steel reuse and proposing actionable strategies for enhancing reutilization rates, this study aims to contribute to the advancement of sustainable construction practices and the promotion of a circular economy. The findings and recommendations of this research can inform policy decisions. They can guide industry practices. They can also inspire further research in sustainable materials management.

1.6. ORGANIZATION OF THESIS

The thesis is structured as follows:

- Chapter 2 provides a comprehensive review of the literature on steel reuse, including an overview of reutilization rates across different countries and an analysis of the factors influencing adoption.
- Chapter 3 presents the methodology employed in this research, outlining the information collection methods, analytical techniques, and proposal development process.
- Chapter 4 presents the findings of the study, including an analysis of barriers to steel reuse and the development of proposals for enhancing reutilization rates.
- Chapter 5 presents recommendation on the studied carried out
- Finally, Chapter 6 offers a conclusion, summarizing the key findings of the research, discussing their implications, and suggesting possibilities for future research.

This thesis endeavors to contribute to the advancement of sustainable practices within the civil engineering sector by proposing actionable strategies for enhancing the reuse of steel products. By addressing the identified challenges and leveraging opportunities for improvement and can move towards a more resource-efficient and environmentally sustainable approach to steel utilization.

2

LITERATURE REVIEW

This chapter serves as a detailed exploration into the ongoing research surrounding the utilization of re-used steel products, their advantageous aspects and the challenges they present. It explores the theoretical framework necessary for addressing the key research questions driving this study, providing a solid foundation for understanding the complexities involved. Furthermore, valuable insights gathered from related studies are also examined and integrated, enriching the discussion and broadening the scope of knowledge on this critical topic.

2.1. TRANSFORMING CONSTRUCTION IN REDUCING GREENHOUSE GAS EMISSIONS

In 2016, the European Union announced its objective of transforming into a low-emission society (FN, 2020). This initiative aims to combat climate change, requiring each member country to develop strategies to reduce greenhouse gas emissions. Norway stands out as one of the most committed nations, aiming to achieve climate neutrality by 2050 (FN, 2020). This ambitious target has driven numerous industries to innovate and adopt new practices to minimize greenhouse gas emissions. The construction industry, which is the subject of this thesis, is among those undergoing significant changes.

Recent research (RICS Professional Standard, 2023; UNEP, 2021) emphasizes the significant impact of building construction on global energy consumption and greenhouse gas emissions, making up approximately 36% and 37% respectively. Of particular concern are the carbon emissions associated from the production of building materials, which contribute around 10% of total emissions (le Den et al., 2022). (Castellano et al., 2014) emphasize the importance of regulatory frameworks like the Energy Performance Building Directive (EPBD) in Europe for guiding sustainable practices and reducing environmental impacts. Cutting down on carbon emissions from making materials and aiming for a circular economy are big reasons why construction methods are changing. But the construction industry also must follow a lot of rules, especially about health, safety, and testing (Ana M. et al., n.d.).

This literature review aims to explore key findings and emerging trends related to energy use, emissions, material utilization, reuse rate of steel in civil engineering industries of different countries and sustainable practices through reuse of steel in construction industries.

2.1.1. THE VALUE CHAIN OF STEEL IN THE CONSTRUCTION INDUSTRY

Research (Smeets et al., 2019), demonstrates the value chain of steel industry from the figure below. The value chain for structural steel outlines the different stages that steel goes through from its raw materials

to the finished product used in construction. The first stage is the extraction of virgin resources. This includes iron ore, which is mined from the ground. The iron ore is then transported to a steel mill where it is turned into molten iron. The molten iron is then refined into steel. The steel can then be used to create a variety of products, including structural steel. Structural steel is used in the construction for various purposes such as making structural members, braces, etc. In between there is also a possibility of reusing and recycling processes for structural steel. This means that steel can be reused and recycled after it has been used in construction. This can help to conserve resources and reduce pollution.

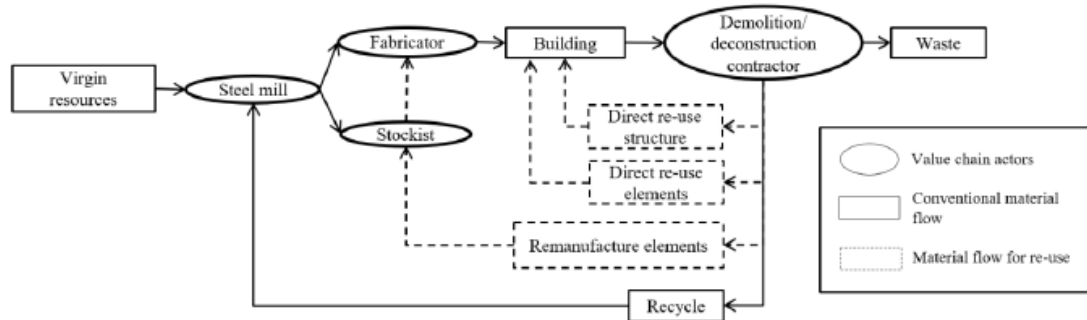


Figure 1 - Structural steel value chain; Source: (Smeets et al., 2019)

Steel production is a major contributor to global energy consumption and greenhouse gas emissions, since steel production worldwide has been increased in a decade from 1995 to 2006, rising from 752 million tons to 1240 million tons respectively, accounting for 5% of total world greenhouse gas emissions (XU & CANG, 2010). And 6.8% of world carbon dioxide emissions (Raggio, 2012). On average globally, producing one ton of steel creates around 2200 kilograms of carbon dioxide, although in many developed countries, it's about 1800 kilograms (IPPC, 2007).

Furthermore, (Lynn K. et al., 2001) discuss that in industrial area, to get a final product, the natural resource are being extracted, then converted into a raw material and then only come to product. They noted that this requires intensive energy, and the five leading energy consumption and carbon dioxide emission industries are iron and steel, chemical, petrol and refining, pulp and paper and lastly the cement industry. Hence, here it is seen that steel industry accounts in one of the leading energy and emission emitters.

Water is crucial in steel manufacturing, being extensively used for cooling, cleaning, and generating steam and in 2011, the typical water usage for each ton of steel made in integrated plants was around 28.6 cubic meters, while the discharged water averaged at 25.3 cubic meters (Conejo et al., 2020). In China, the steel industry makes about half of the world's steel, and it typically uses 7–8 cubic meters of water for each ton of steel produced, which is more than the 3–4 cubic meters used by developed countries (Gao et al., 2011). Looking at this number, another associated problem of steel production seems to be the water consumption and resource inefficiency.

2.1.2. THE VALUE CHAIN OF STEEL IN THE CONSTRUCTION INDUSTRY

According to (Bo Björkman & Caisa Samuelsson, 2014), steel recycling is a crucial aspect of the steel industry, with significant potential for energy and emissions savings. It further notes that, to recycle a steel in manufacturing of new steel, a steel scrap is collected and undergoes either to an electric arc furnace (EAF), which is termed as scrap-based steelmaking, or to the basic oxygen furnace (BOF), which is termed as ore-based steelmaking. They further emphasized the importance of scrap that in the western Europe 55% of steel is manufactured from scraps.

Let's start with the figures on consumption rate of ferrous scrap across the world between the year 2017 to 2021. The report from (Bureau of International Recycling Ferrous Division, 2022), aims to improve ferrous scrap figures, including quarterly updates of world statistics. According to the document, significant consumption of ferrous scrap occurs in seven primary countries which are China, EU-27, USA, Turkey, Japan, Russia and Republic of Korea, and the review of their studies showcases significant changes in steel scrap usage and crude steel production in these countries.

The following important information can be gathered from the table:

- China seems to have had the most scrap consumption (226.21 million tonnes) but also the biggest decline of 2.8% on scrap consumption.
- The EU-27 has the second highest scrap consumption (87.853 million tonnes) and the highest increase in percentage of scrap consumption which is 16.70%.
- The USA comes in third in scrap consumption (59.4 million tonnes) and has a high increase in percentage scrap consumption (18.30%).

Table 1 - Countries with Scrap production and consumption; Source: (Bureau of International Recycling Ferrous Division, 2022)

Country	Change in Scrap Consumption	Scrap Consumption	Proportion of Scrap	Change in Crude Steel Production
China	-2.80%	226.21 million tonnes	21.90%	NA
EU-27	16.70%	87.853 million tonnes	57.60%	15.40%
USA	18.30%	59.4 million tonnes	69.20%	18%
Turkey	15.70%	34.813 million tonnes	86.10%	12.70%
Japan	19%	34.727 million tonnes	NA	15.80%
Russia	7%	32.138 million tonnes	41.70%	5%
Republic of Korea	9.50%	28.296 million tonnes	40.10%	5%

Table 2 – 12 largest steel-producing countries and their production figures from 2017 to 2021; Adaption: (Bureau of International Recycling Ferrous Division, 2022)

Rank	Country	2017	2018	2019	2020	2021
1	China	870.9	920	995.4	1064.8	1032.8
2	India	101.4	109.3	111.3	100.2	118.1
3	Japan	104.7	104.3	99.3	83.2	96.3
4	USA	81.6	86.6	87.8	72.7	86
5	Russia	71.6	72.8	72	73.2	76

6	Republic of Korea	71	72.5	71.4	67.1	70.6
7	Turkey	37.5	37.3	33.7	35.8	40.4
8	Germany	43.3	42.4	39.7	35.7	40.1
9	Brazil	34.4	35.4	32.6	30.9	36
10	Iran	21.2	24.5	25.6	29	28.5
11	Taiwan	22.4	23.2	22	20.5	23.2
12	Ukraine	21.4	21.1	20.8	20.6	21.4

Table 3 - the world crude steel production by the Basic Oxygen Furnace (BOF) and Electric Furnace (EF) processes; source: (Bureau of International Recycling Ferrous Division, 2022)

Region/Country	BOF (Million Tonnes)	EF (Million Tonnes)	BOF (% of Total)	EF (% of Total)
European Union (28)	91.5	68.3	57.3	42.7
Other Europe	13.7	31.4	30.4	69.6
of which Turkey	11.5	28.9	28.4	71.6
C.I.S.	65.2	34.8	61.8	33
of which Russia	44.6	29.5	59	39
North America	36.5	81.4	31	69
of which USA	26.5	59.3	30.8	69.2
South America	30.8	14.2	67.7	31.3
Africa	3.4	17.1	16.1	83.9
of which South Africa	2.9	2.1	57.7	42.3
Middle East	2.8	43.1	6	94
of which Iran	2.8	25.7	9.7	90.3
Asia	1132.8	270.2	80.7	19.3
of which China	923.5	109.3	89.4	10.6
of which India	53	65.2	44.8	55.2
of which Japan	71.9	24.4	74.7	25.3
of which Republic of Korea	48	22.4	68.2	31.8

Oceania	4.9	1.5	76.2	23.8
of which Australia	4.3	1.5	73.6	26.4
World	1381.5	562.7	70.8	28.9
Total 64 Countries				

Looking at the data in the table above, most of the developed countries rely much more on scrap metal to produce new steel rather than exploiting more natural resources. On the other hand, the developing countries seem to rely more on the primary ore as a production of the steel. The data of Electric Furnace production percentage of Asia is seen as 19.3% and compared to EU-28, their production percentage seems to be much higher accounting to 42.7%.

(Dr Baris Bekir Çiftçi, 2018) shows that about 750 million metric tons of ferrous scrap were available globally in 2017, with 630 million metric tons recycled by the steel and foundry casting industries. Their studies expect this availability to increase to 1 billion metric tons by 2030 and 1.3 billion metric tons by 2050, meaning a growth of over 500 million metric tons in the next 30 years as shown below. He further emphasized that the significant increase in scrap availability indicates that over time, steel industry will rely more on steel scrap instead of natural resources. This shift will help conserve raw materials and energy while also reducing CO2 emissions.

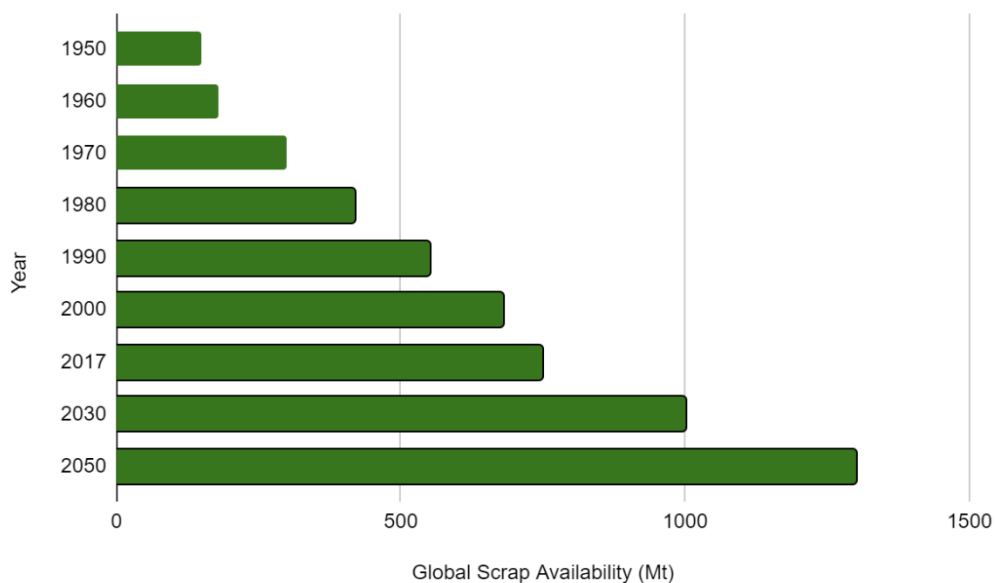


Figure 2 – Bar Graph showing the predicted global scrap availability within 2050; adapted: (Dr Baris Bekir Çiftçi, 2018)

In UK, there's a significant difference in price between new steel sections, which cost between £1000-1500 per ton, and steel scrap, priced at around £100-200 per ton, even after considering all handling expenses (Smeets et al., 2019).

2.2. THE ENVIRONMENTAL AND ENERGY BENEFITS OF STEEL RECYCLING AND REUSE

According to (World Steel Association, 2015), their target to recycle steel in the construction industry by 2050 seems to be 90%, but looking at the data, the recycling industry specifically the construction industry has already achieved 85 % in 2007 indicating a promising progress.

Table 4 - Recycling rate of steel industry; source: (World Steel Association, 2015)

Application Area	Estimate for 2007 (%)	Target for 2050 (%)
Construction	85	90
Automotive	85	95
Machinery	90	95
Appliances	50	75
Containers	69	75
Total	83	90

It seems that steel recycling could be a solution to reduce energy consumption, carbon emissions and most importantly minimizing the new production of resources. According to (Norgate et al., 2007), when recycling was done in a steel industry, it was found that about 50% of the energy was being saved and nevertheless, still recycling of steel was seen as energy and carbon intensive process. And further 75% of the new resource production was being saved when recycle (Key Statistics, 2016). Moreover (Michał P. Drewniak et al., n.d.), note that reusing steel instead of using newly produced steel, whether primary or secondary, is a great way to decrease the CO₂ emissions associated with construction. It conserves both the energy and carbon needed to melt the scrap and reshape it into a usable product (Ellen MacArthur Foundation, 2015). (Densley Tingley et al., 2017), defines reuse as using something again after its initial use, usually with small changes, which helps to keep its carbon footprint low and further says that unlike recycling, where materials are often melted down, reusing steel doesn't involve melting it.

It could be noted that reuse has a bigger impact on saving energy and controlling emissions as well as conserving natural resources. The Environmental Product Declaration (EMR, 2023) shows that reused steel has a Global Warming Potential (GWP) of around 50 kgCO₂e/t during stages A1-A3 of its lifecycle. This suggests significant environmental benefits, with potential GWP reductions of up to 95%, 90%, and 75% compared to primary steel production, recycled steel, and renewable energy-based recycled steel, respectively (International EPD System, 2022).

Despite its benefits, Yeung et al. (2017) raise questions: Why isn't there a higher adoption rate of structural steel reuse? Why hasn't the global adoption of steel reuse been more widespread? Is there enough global information available on steel reuse? To explore this further, an extensive overview of the reuse rate of steel in different countries was carried out. The information search focusing on countries such as the UK, Germany, Canada, Belgium specifically chosen due to the availability of pertinent data on the reuse rate of steel.

2.3. STEEL REUSE RATES IN DIFFERENT COUNTRIES: AN OVERVIEW

In general, (Bassam A. & Michael R. Sansom, 2006) present comprehensive insights into the recycling rates of construction materials derived from construction and demolition waste. Their study, as shown in Table below, gives more information on the different rates of recycling observed across different European countries.

Table 5 - different rates of Reuse and recycling of construction material observed in different European countries; Source: (Bassam A. & Michael R. Sansom, 2006)

Member state	"Core" construction and demolition waste	% re-used or recycled	% incinerated or landfilled
Germany	59	17	83
UK	30	45	55
France	24	15	85
Italy	20	9	91
Spain	13	<5	>95
Netherlands	11	90	10
Belgium	7	87	13
Austria	5	41	59
Portugal	3	<5	>95
Denmark	3	81	19
Greece	2	<5	>95
Sweden	2	21	79
Finland	1	45	55
Ireland	1	<5	>95
Luxembourg	0	N/A	N/A

A project funded by the ECSC and carried out by steel producers and construction institutes in the Netherlands, Sweden, and the UK aimed to understand and quantify the environmental impacts of steel in construction (E. Durmisevic & Nico Noort, n.d.). Their project was carried out by analyzing the end-of-life results of steel products, the project seeks to increase their reuse potential to reduce environmental impacts. They found in their studies that, at the end-of-life cycle of steel structure, 83% of steel construction products are recycled, 14% are reused, and only 3% are sent to landfills. This information was further shown in detail in the table below and seen in which steel product is being recycled and reused the most. They further define a steel product as a closed- loop material cycling since steel consistently maintains its value, and its material properties are preserved, resulting in minimal down-cycling.

Table 6 – Type of steel product which is being recycle and reuse most; Source: (E. Durmisevic & Nico Noort, n.d.)

Product	Recycling (%)	Re-use (%)	Landfill (%)
Girders	88	8	4
Lintel	88	10	2
Road barrier	65	34	1
Post coated inner wall components	59	7	34
Doorframes	90	9	1
Insulated inner wall box	87	11	2
Metal stud wall	92	7	1
Services	87	11	2
Light gauge steel (housing)	87	11	2
Purlins and rails	87	11	2
Composite floor decking	81	15	4
Composite sandwich cladding panels	53	37	10
Roof plate (coated)	81	15	4
Profiled cladding and roofing panels	81	15	4
Heavy structural sections	87	11	2

2.3.1. STEEL REUSE RATES IN THE UNITED KINGDOM

A survey from (Sansom & Avery, 2014), conducted among UK demolition contractors to estimate the reuse and recycling rates of steel construction products arising from the demolition of buildings in UK. According to these studies, the UK and EU are increasingly focusing on recovering and reusing materials from demolished buildings instead of sending them to landfills.

Their studies conducted two surveys in England and these two surveys were compared. One was in 2000, the Steel Construction Institute (SCI) conducted a survey among UK demolition contractors, aiming to estimate the recycling and reuse rates of common steel construction products. Their survey sent 160 questionnaires to National Federation of Demolition Contractors (NFDC) members, and of 160, 44 responses were received, covering 5,430 buildings. On the other hand, in July 2012, Tata Steel conducted a survey in the UK as part of a Eurofer initiative aimed at quantifying the percentage of steel recovered from typical building demolition sites. The survey involved sending questionnaires to 160 National

Federation of Demolition Contractors (NFDC) member companies, resulting in 32 completed responses, representing a return rate of 20%.

Table 7 - Overview of the reuse and recycling percentages derived from the 2000 survey conducted by the Steel Construction Institute; Source: (Sansom & Avery, 2014)

Type of Steel	Structural Steel	Secondary Structural Steel	Cladding	Composite Floor Decking	Rebar	Internal Non-Structural Steel
Recycling Rate	86%	89%	79%	79%	88%	85%
Reuse Rate	12%	10%	15%	6%	2%	2%
Landfill Rate	1%	1%	6%	15%	8%	13%
Export Rate	1%	-	-	-	2%	-

Table 8 - Overview of reuse and recycling percentages based on the 2012 Eurofer survey; Source: (Sansom & Avery, 2014)

Product	% Reused	% Recycled	% Lost
Heavy structural sections/tubes	7	93	0
Rebar (in concrete superstructure)	0	98	2
Rebar (in concrete substructure or foundations)	2	95	3
Steel piles (sheet or bearing)	15	71	14
Light structural steel (e.g. galvanized purlin, supports, etc.)	5	93	2
Profiled sheet cladding (roof/façade)	10	89	1
Internal light steel (e.g. plaster profiles, door frames)	0	94	6
Other (e.g. stainless steel if different from above)	3	96	1
Average (across all products)	5	91	4

In comparing the two tables, there's an evident increase in overall recycling rates between the 2000 and 2012 surveys:

- Table 7 from the 2000 survey demonstrated an average recycling rate of 84.3 % across all products.
- Table 8 from the 2012 survey indicated a rise to 91% in recycling rates.

Conversely, there was a similar reuse rate seen in the 2012 survey:

- Table 7 of the 2000 survey displayed an average reuse rate of 10 -12 %
- Table 8 of the 2012 survey showed a similar reuse rate of 10-12% and decrease in the waste to landfill.

(Michal P. Drewniok et al., n.d.) point out in their studies that the low adoption of steel reuse in UK construction could be due to limited market availability and higher costs. They emphasize that reusing steel in the UK is slightly more expensive than using new steel, with a marginal difference of 10%.

2.3.2. STEEL REUSE RATES IN GERMANY

(Kamrath, 2023) carried a study to find out techniques as an alternative of demolition and recycling to see its limits and benefits of reusing steel in the construction industry. Most of the historical buildings in Germany when accounted for demolition, average life span of the scenario data is show in the table below.

Table 9 – Material obtains from one of the demolished buildings to see what materials can be recycle, reuse or goes to landfill; Source: (Kamrath, 2023)

Material	Recycling (%)	Reuse (%)	Landfill (%)
Girder	88	11	1
Lintel	88	10	2
Road barrier	65	34	1
Post coated inner wall components	59	7	34
Doorframes	90	9	1
Insulated inner wall box	87	11	2
Metal stud wall	92	7	1
Services	87	11	2
Light gauge steel (housing)	87	11	2
Purlins and rails	87	11	2
Composite floor decking	81	15	4
Composite sandwich cladding panels	53	37	10
Roof plate (coated)	81	15	4

Their project highlights a single-story hall, once part of an old fabrication plant in Wuppertal, Germany, was scheduled for demolition. However, due to its historical significance, efforts were made to preserve at least the roof structure, which had been integrated with the office building's construction. This preservation was important as the hall marked the beginning of the company's operations. To proceed with this project, they use a technique of deconstruction rather than demolition. Their studies define deconstruction as a method aiming to preserve as much of the structure as possible for future use during the demolition phase.

At the end of this project, it was seen that reuse is hard because of technical and high cost. Buildings with screws are easier to take apart and reuse. If there's less concrete, it's easier to reuse. To take a building apart, it is seen that it needs cranes instead of excavators. Single-story halls with cladding on a screwed steel structure are best for reusing. It takes longer time and costs more to take buildings apart

compared to just demolishing them down. People usually just tear buildings down to build new ones. It's cheaper because steel parts can be sold for recycling. Figure below shows the overview of how the project was carried out.

(Anna Kuehlen et al., n.d.), emphasizes further that the main challenges for deconstruction of existing building in Germany not made in their design for the purpose of safely dismantled of building parts in later use. Even if it is made for proper deconstruction in later use, it is seen that there isn't available of proper machinery to dismantle it and eventually disposal to landfills is seen more economical, rather than time consuming during the separation of materials.

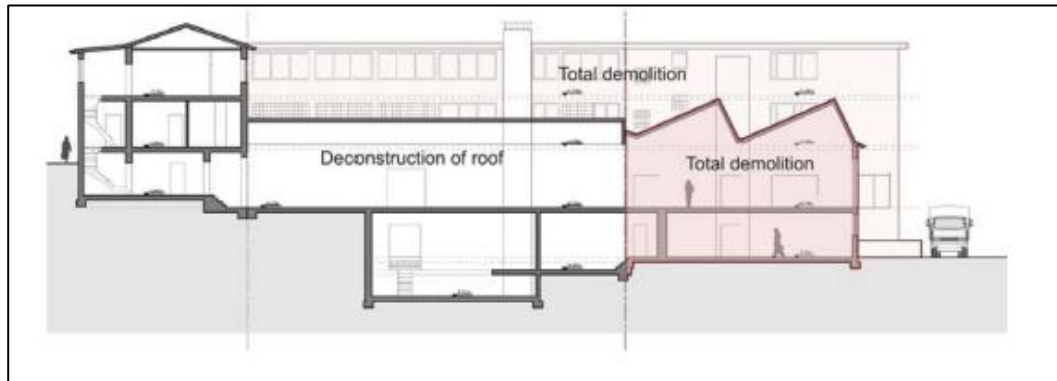


Figure 3 – Sectional view of demolition and deconstruction building project in Germany; Source: (Anna Kuehlen et al., n.d.)



Figure 4 – Deconstruction of building using crane; Source: (Anna Kuehlen et al., n.d.)



Figure 5 – Reclaim steel-based roof structure after deconstruction method; Source: (Anna Kuehlen et al., n.d.)

2.3.3. STEEL REUSE RATES IN CANADA

(Dr Mark Gorgolewski et al., n.d.) discusses a project carried out by the Department of Architectural Science at Ryerson University, funded by the Enhanced Recycling Component of the Government of Canada Action Plan 2000 on Climate Change and the Canadian Institute for Steel Construction. To see the quantitative data on reuse of steel in Canada based construction, their studies found that in Canadian construction industries, most steel from demolished structures, around 90% of it is recycled, with half going back to steel mills, while the rest is sorted into different recycling methods. Another 9-10% is reused in various ways, while less than 1% ends up in landfills because it's hard to separate from other waste.

Based on their project, numerous barriers were identified in Canada that hindered the adoption of steel reuse, which may also be applicable to other parts of the world. (Dr Mark Gorgolewski et al., n.d.), highlighted some of the following barriers that restricted the adoption of reuse of steel.

- Reusing building components in their original condition can be complicated. Engineers may hesitate to approve them because they haven't been tested to current standards and their specifications aren't immediately available, raising liability concerns. Testing reclaimed steel components for safety can be costly, sometimes making them as expensive as new components.
- There's generally little awareness in the construction industry about the potential for reusing materials as they are, which can lead demolition to work quickly and remove components without consideration for reuse.
- The availability of building components for reuse can be unreliable, leading to higher planning and storage costs for new construction projects. Sometimes, there may not be enough of a specific component type available, requiring adaptable designs.
- The high price of scrap steel makes reusing steel components less attractive. Contractors often prefer sending reclaimed steel directly to recycling facilities, as it saves time, storage costs, and provides immediate income for projects.
- Welded joints in structural steel components can complicate deconstruction, often requiring careful removal through grinding and cutting (Canadian Standards Association, 2012)

2.3.4. STEEL REUSE RATES IN BELGIUM

In Belgium there isn't any research conducted to find out the reuse rate of steel in their construction industries. Nevertheless, researcher felt the importance of reuse of steel in construction industries, therefore, (Anastasiades K. et al., 2022) discusses the barriers of steel reuse within the Belgian construction industry. Their research consists of two main parts. Firstly, the views and opinions of various stakeholders were gathered through semi-structured interviews, identifying cost, demand, and time as the main barriers. Secondly, these barriers were further explored through a case study involving the demolition of a steel shed. The study examined both destructive removal and disassembly of steel beams, revealing that cost shouldn't be a significant barrier if the disassembly is carried out efficiently by the expert demolition role players. However, the most critical barrier appeared to be the lack of demand for reusable steel beams, as they couldn't be sold except as scrap metal due to the absence of suitable platforms for resale. The research also highlighted failings in regulations governing these platforms. Additionally, time constraints imposed by the client were identified as an issue, limiting the exploration of various disassembly scenarios.

2.4. BENEFITS AND CHALLENGES OF STEEL RECYCLING: A GLOBAL PERSPECTIVE

According to (World Steel Association, 2021) recycling steel scrap from products after they've served their purpose to make new steels involves changing the physical shape of the steel object. They emphasize that this process preserves the original steel's properties while allowing it to be used for a new purpose. Their research highlights various advantages of recycling steel and its demand as follows.

- Steel has always been recycled since it was first made, creating a continuous loop where all available scrap is reused.
- Recycled steel keeps its original properties and can be changed to produce different types of steel.
- Its high scrap value makes recycling economically viable, and its magnetic properties make it easy to recover.
- Recycling steel prevents significant CO₂ emissions, but there isn't enough scrap to meet the demand for new steel.
- While some steel products have short lifespans, others like buildings are meant to last for decades or centuries and will eventually be recycled to make low-carbon steel.

Globally, energy and emissions are seen as a problem and the steel industry has managed to tackle those problems efficiently as the figure below illustrates.

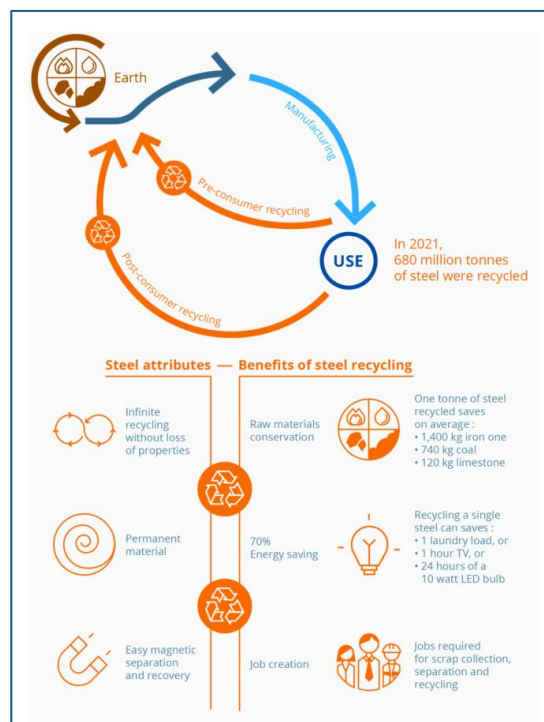


Figure 6 –Benefit of Steel Recycling; Source: (World Steel Association, 2021)

It is seen from the review of different countries that market demand, companies' awareness and time consumption are seen as another major factor. While recycling steel appears to be more straightforward than reusing it. It is further seen that based on literature surveys in European countries, there is limited data on steel reuse rates in different countries which can be drawn into conclusion that there might be lack of awareness and demand for reused steel, with recycling being more predominant due to the robust scrap market worldwide. Even researchers are exploring strategies to address barriers and find solutions to increase the scale of reuse, if not surpass the current rate.

It can now further conclude that reusing steel in buildings could help a lot, but according to (Danielle Densley Tingley & Julian Allwood, 2014), the reuse rate of steel is influenced by five key factors to be considered, which are:

- Not enough materials available,
- Making sure to reuse as much as possible from demolitions,
- Not having clear design rules and standards,
- Initial expenses being high and neglecting the carbon footprint of demolition before building begins.
- Engagement and Coordination of entire construction process

2.4.1. CHALLENGES WITH DESIGN RULES AND STANDARDS

One of the problems related to reuse of steel known from the studies of (Danielle Densley Tingley & Julian Allwood, 2014) was not having clear design rules and standards. (H.Bartsch et al., 2023) studies emphasizes that steel reuse was common after World War II due to material shortages, it became less common with economic growth. However, various standards and guidelines from historical and current standards, along with ongoing and finished research projects, were summarized and need for the development of guidelines for reusing steel structures and components were addressed by their studies.

Their research indicates that in Germany, the reuse of "Old Steel" is guided by historical standards outlined in DIN 1050 Blatt 2 from 1947. Old Steel here refers to steel salvaged from demolished structures, such as steel bars, shaped steel, or plates. The standard permits the reuse of old steel in new structures primarily under static loads, but it must be labeled accordingly shown in figure below, which includes details about the company, the engineer in charge of overseeing the proper handling of the old steel, and the specific label required by the DIN 1050 Blatt 2 standard from 1947.



Figure 7 – Marking of an Old steel as per DIN 1050 Blatt 2, 1947 code; Source: (H.Bartsch et al., 2023)

Note: Table below highlights how the historical standards for reuse of steel are being used.

- prEN 1090-x is a standard under development for reuse of steel structures and components.
- Group A-D refers to the evaluation procedures outlined in the future standard (prEN 1090-x).
- prEN 17662 (2021) promotes including sustainability and reusability options in steel product declarations

Table 10 – Historical Standard Summary for its usage; Source: (H.Bartsch et al., 2023)

Label Criteria	Category	DIN Standard (Reuse)	Reuse Guidance (Current Standards)	Testing Methods (Current Standards)	Deconstruction & Testing (Future Standard)	Evaluation Scheme (Future Standard)
Production year < 1900 (+ "S" label) OR Flange rusting < 10%	I	1050 (Full)	ANSI/AISC 360-16 (Non-structural)	Annex 5 (Destructive)	Deconstruction rules	Group A-D (Documentation & Testing)
Flange rusting 10-25%	II	1050 (80% Reduction)	ANSI/AISC 360-16 (Non-structural)	Annex 5 (Destructive)	Deconstruction rules	Group A-D (Documentation & Testing)
Flange rusting > 25%	Not Reusable	-	-	-	-	-

On the other hand, in 2014, CE-marking rules in construction have become more important. Now, fabricators must certify that all steel structures are suitable. Knowing the age and maker of elements can guide in finding their properties in guides like the 'Blue Book' or 'Green Book' from the Steel Construction Institute.

Further design regulations are now already there for making the reuse of steel efficiently. European developments like prEN 1090-x emphasize re-use in construction by providing rules for testing material properties, de-mounting structures, and handling tolerances (prEN 1090-x, 2022). Similarly, American standard ANSI/AISC 360-16 also focuses on re-use in construction, providing guidelines for structural steel design and construction, including provisions for re-using components (Vares, Hardil, et al., 2020). Additionally, a guideline according to (Pimentel et al., 2019) provided by the Steel Construction Institute offers design principles for various load situations and general guidelines regarding the reuse of steel components. There are other additional documents related CE marking in accordance with EN 1090-2 (EN 1090-2, 2018). Lastly important document such as guidelines and standards for retrofitting existing structures are mentioned, in RIL DS 805 in Germany (Deutsche Bahn Netz AG, 2021) and ONORM B 4008-1 in Austria, focusing on load capacity assessment and recalculation schemes (ÖNORM B 4008-1:2018-10, 2018).

It is further clear that if the reclaimed steel passes the technical delivery standards, then the codes and regulations mentioned above can be used to design any structures using reused steels following the labelling of it to identify for future cause.

2.4.2. COST AS A BARRIER TO STEEL REUSE

(Wang et al., 2017) conducted a cradle-to-cradle model that includes every step of steel production and considers both the movement of materials and changes in the steel market. While conducting their

model, they found that the cost factor is important to determine this model. Therefore, in the absence of official statistics, the cost structure of Chinese steel production is estimated using market prices for raw materials and energy, alongside data from previous studies for other costs like labor and investment. Additionally, energy consumption patterns are analyzed based on a separate study, while prices for key inputs are sourced from the UN Comtrade database. They found that the cost of production of new steel in Table below using scrap material which is secondary production seems to show slightly higher cost than primary production of steel. They further noted that secondary production is simpler to manage and more environmentally friendly. In the future, using old scrap instead of ore will become more popular due to an abundant supply of old scrap and a shortage of ore resources, resulting in the gradual increase of secondary production (Yellishetty et al., 2011).

Table 11 – Cost for Steel Production through primary and secondary route; Source: (Wang et al., 2017)

Contents	Unit Cost (\$ per GJ or ton)	Primary Production Route		Secondary Production Route	
		Factor	(Total Cost \$ per ton of final product)	Factor	(Total Cost \$ per ton of final product)
Fuel	4.72	16.02	76	1.2	5.8
Electricity	16.8	1.78	30	4	67.2
Iron Ore	304.7	1.48	450	1.06	0
Steel Scrap	609.4	0	0	1.06	645.5
Labor Cost	-	-	15	-	10
Capital Charges	-	-	50	-	30
Other Cost	-	-	60	-	50
Total	-	-	681	-	698.5

(Vares et al., 2019) conducted a study, part of the PROGRESS (Ana M. Girão Coelho et al., 2020) project, looks at the environmental impact and cost of using steel structures in industrial buildings. It compares the effects and expenses of using new materials over reusing steel components. The study was based on Life Cycle Assessment (LCA) for a single-story industrial hall located in Finland and the building consists of steel portal frames, secondary structural elements such as purlins, side rails, and bracing, and the envelope which is made of steel sandwich panels with mineral wool insulation. During their studies, they found the total cost of construction of a new industrial building and the cost of building made from reused steel following the ISO 15686-5 standards. Their findings, as shown in table below, demonstrate that the cost of building a structure from reclaimed steel as well as the environmental impact seem slightly lower and cheaper than constructing newer steel buildings. Moreover, their study finds that reusing steel reduces greenhouse gas emissions by about 170 kilograms of CO₂ per square meter, totaling 80.9 metric tons of CO₂, compared to using new steel for the entire building's life cycle. This difference isn't huge, only around 12%, because the steel industry often incorporates recycled steel into new production.

Table 12 – Life Cycle Assessment Results of the studies carried out by Vares and Team; Source: (Vares et al., 2019)

Product	New building (tCO ₂ e/27yr)	Reused steel (tCO ₂ e/27yr)
Product stage (A1-3)	180.1	90.7
Frame	2.3	2.3
Purlins and rails	14.3	1.5
Bracing	3.1	3.1
Envelope	57.1	0.3
Concrete and EPS	81.6	81.6
Reconditioning	0	0.4
Windows	0.4	0.4
Doors	0.5	0.5
Construction (A4-5)	14.4	14.4
Transport	2.5	2.6
On-site energy	0.9	0.9
Crane	6.5	6.5
Forklifts	1.4	1.4
Man-lifts	2	2
Excavator	0.9	0.9
Use stage (B6)	481	481
Demolition (C1, C2)	10.8	19.3
Transport	0	0.4
On-site energy	0.9	0.9
Crane	6.5	13.1
Forklifts	2	2
Man-lifts	1.4	2.8
Total (A-C)	656.2	605.3

Table 13 - Life Cycle Cost Results of the studies carried out by Vares and Team; Source: (Vares et al., 2019)

Product	New building (€/27 yr)	Reused steel (€/27 yr)
Product stage (A1-3)	99 000	75 000
Inventory	6 000	
Planning	9 000	10 000
Demolition		9 000
Steel panels	51 000	0
Steel frame	16 000	0
Concrete + EPS	8 000	8 000
Windows + door	15 000	15 000
Reuse price	0	27 000
Construction (A4-5)	24 000	31 000
Use stage (B6)	205 000	205 000
Demolition (C1, C2)	9 000	9 000
Total (A-C)	337 000	320 000

In one of the Case studies for the NTS building project carried by (Danielle Densley Tingley & Julian Allwood, 2014) in Figure below, highlights that these practical examples also demonstrate that using steel again can greatly cut down on the carbon emissions and expenses involved, while also helping to save materials and decrease waste as shown in table below.



Figure 8 – NTS Building Research Project; Source: Cleveland Steel & Tubes Limited

Table 14 - Cost and carbon saving summary of NTS building project; Source: Cleveland Steel & Tubes Limited

Category	Cost if new	Additional cost of reuse	Cost saving versus new	Net saving	Carbon saving (approx.)
Design/admin	£312,000	£26,000	£162,000	(£26,000)	n/a
Groundworks	£422,000	0	Plannings = £130,000 Mucking= £133,000	£260,000	Haulage-224 T CO ₂ , Stone-52 T CO ₂ ,
Steel	£1,020,000	£160,000	£566,000	£566,000	1000 T CO ₂
Cladding	£740,000	n/a	n/a	n/a	n/a
Floor	£950,000	n/a	n/a	n/a	n/a
Landscaping	£150,000				
Foundations	£132,000		Muck-6000	£4000	4 T CO ₂
Erection	£239,000	n/a	n/a	n/a	n/a
Totals	£3,776,000		£995,000	£969,000	1480 T CO ₂

In (Vares, Hradil, et al., 2020) another study using data of one-story factory construction in Finland from the Project PROGRESS (Ana M. Girão Coelho et al., 2020). The research looks at how much it costs to own and run a one-story factory in Finland, as well as how it affects the environment. The main aim was to compare the effects of using steel again over building with new steel or reused steel parts. Table X provides the life cycle cost findings for the various stages of the building's life (from A1 to D). Their studies further emphasize that when the building is demolished or taken apart, its remaining value is figured out by subtracting the demolition expenses from the income generated by selling materials like steel scrap or reusable parts. Different scenarios were explored as per table X and found that using steel again saves 5,521 euros and 4,315 euros compared to using new steel and then recycling it after the building's life.

Table 15 - Life Cycle Cost (LCC) analysis for the construction of a new steel hall and for the construction of a steel hall using reused steel components; Source: (Ana M. Girão Coelho et al., 2020)

LCC stage	New steel demolition and recycling	New steel deconstruction and reuse	Reused steel demolition and recycling	Reused steel deconstruction and reuse
Initial and future value	G4-G4	G4-G1	G1-G4	G1-G1
Product stage (A1-3)	108,191	108,397	102,670	103,876
Steelwork design	959	1165	1165	1370
Other engineering tasks	8000	8000	8000	8000

Steel panels	51,050	51,050	51,050	51,050
Steelwork	19,782	19,782	15,056	15,056
Concrete and EPS	19,600	19,600	19,600	19,600
Windows and doors	8800	8800	8800	8800
Testing/reconditioning	22,378	0	4727	4727
Construction (A4-5)	22,378	22,378	22,378	22,378
Steelwork assembly	7878	7878	7878	7878
Other construction tasks	14,500	14,500	14,500	14,500
Use stage, 27 years (B6)	205,000	205,000	205,000	205,000
Demolition (C1-2)	12,569	17,144	12,569	17,144
Pre-demolition audit	3000	6000	3000	6000
Steelwork demolition	4569	6144	4569	6144
Other demolition tasks	5000	5000	5000	5000
Total costs (A-C)	348,138	352,919	343,617	348,398
Potential savings (D)	-2740	-11,549	-2740	-11,549
Total costs including potential savings (A-D)	345,398	341,369	340,877	336,849

Table 16- Estimated value of the new hall and the steel hall with reused steel components; Source: (Ana M. Girão Coelho et al., 2020)

LCC stage	New steel demolition and recycling (€)	New steel deconstruction and reuse (€)	Reused steel demolition and recycling (€)	Reused steel deconstruction and reuse (€)
Initial value (A1-5)	130,569	130,774	126,048	126,253
Demolition cost (C1-2)	12,569	17,144	12,569	17,144
Revenue	2740	13,480	2740	13,480
Residual value (revenue minus demolition costs)	-9829	-3664	-9829	-3664
Depreciation rate, 27 years	4.00%	3.80%	4.00%	3.80%

When looking at the information from the studies that already done, if a new building is constructed using reuse steel, it is seen that it saves cost as well as environment burden but (Ana M. Girão Coelho et al., 2020) emphasizes that despite of its advantages such as recovering material efficiently using components or whole structures and preventing waste and in return it usually needs more money upfront. The increased initial expense associated with reuse comes from conducting quality checks, manual labor during dismantling, storage, and transporting over long distances (Danielle Densley Tingley & Julian Allwood, 2014). Even the research conducted on the case studies mentioned earlier was part of an invested or funded project aimed at constructing new buildings using either reuse of steel gathered from demolition waste or waste from yards.

2.4.3. AVAILABILITY OF REUSE MATERIALS AND LIMITED MARKET DEMAND

One of the identified problems for the reuse of steel is the lack of available materials and no market demand for it. For instance, (Fujita & Iwata, 2008) proposed a reuse system in steel construction and this system involves a complete business setup shown in figure below, that ensures a continuous cycle of reuse from design to demolition, including storing reusable parts, which can be a solution for this problem. Their studies note that to establish this system, several elements need development or implementation, such as maintaining a stock of reusable parts, creating a reuse management model, setting up a database process, creating storage locations, conducting careful demolitions, evaluating reusable parts' performance, and developing fabrication procedures. Furthermore, the dotted line in figure below represents information flow, while the solid line indicates the movement of reusable parts. These parts circulate through a cyclic process via the database, passing through stages of design, fabrication, construction, maintenance, demolition, and storage.

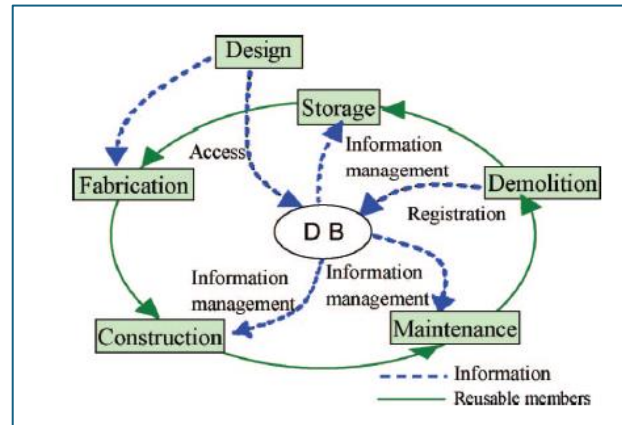


Figure 9 – Reuse Flow Diagram; Source: (Fujita & Iwata, 2008)

Their studies further suggest that creating a venous industry focused on disposal, recycling, and reusing of products to enable the circulation of structural members as reusable components. They define venous industry as a cyclic flow that deals with recycling and reusing construction materials like steel, aiming to create a sustainable cycle of reuse and reduce waste, like how veins recycle blood in the body.

2.4.4. INTEGRATING RFID AND BIM IN SMART STEEL APPLICATIONS

Other studies from (Ness et al., 2015) identifies the need for improving resource efficiency. The challenge of tracking and importing steel components into virtual models for new buildings. The lack of quantifiable data on the stress properties of steel over its working life for best practice reuse of resources.

Their studies highlight the need for new business models and opportunities in the steel industry. Their studies initially explore the potential of merging Radio Frequency Identification (RFID) technology and Building Information Modeling (BIM) to track and import steel components into virtual models for new buildings. This integration, known as "Smart Steel," enables designers to locate and import components and assemblies from nearby areas. Furthermore, the study proposes the incorporation of stress sensors into steel components, a measure that could revolutionize the understanding of steel's stress properties throughout its operational lifespan. By providing insights into structural integrity and suitability for reuse, this data promotes best practices in resource management.

If this initiatives trends, then this might solve the problem related to tracing of materials and its information which might create a demand for steel reuse from a database management monitoring system. Looking at this, the problem related to availability of reclaim steel might not solved significantly, since the design life span of steel building are shown in table below, and these proposed systems are for tracking resources used for newer building rather than using reclaim steel and making it.

Table 17 - Lifespan of steel product; Source: (ING, 2023)

Major Steel Goods	Recycling Rates (%)	Lifespan (Years)
Vehicles	95	20
Industrial Equipment	97	50
Cladding	85	40
Reinforced Steel	50	50
Infrastructure	80	60
Structural Steel	95	50
Packaging	60	1
Appliances	95	14
Other	85	20

2.4.5. DESIGNING FUTURE BUILDINGS FOR REUSABILITY WITH DESIGN FOR DISASSEMBLY (DFD)

The studies, from (Broniewicz & Dec, 2022), conducted an assessment of the environmental impact associated with three scenarios concerning the demolition and operation of a steel structure. Scenario 1 with complete re-melting, Scenario 2 with partial reuse of construction elements and remelting, and scenario 3 with complete reuse of the structure. The results from this study indicate, scenario 3 exhibits the lowest environmental impact among the three scenarios, showcasing a reduction of over 70% compared to Scenario 1. This studies further emphasizes that complete reuse of the steel structure in Scenario 3 eliminates the need for remelting and fabrication of new sections, resulting in significant energy savings and reduced greenhouse gas emissions. Studies highlight that steel's inherent durability facilitates partial or full product reuse at the end of their lifecycle, effectively prolonging the life cycle of steel products. However, achieving successful reuse necessitates initial design considerations fixed in life cycle thinking and accounting for factors such as legislation, policy, and the design process. The study precisely analyzed the end-of-life phase of a dismantled steel structure, emphasizing reuse within a circular economy framework. This involved evaluating both the product and construction process stage

alongside the end-of-life stage, including the demolition process. The insights derived from the analysis of demolition and reuse processes can significantly contribute to designing new buildings incorporating Design for Disassembly (DfD) principles. Particularly, prior research often neglected the demolition stage in studies on the end-of-life phase of building structures, crucial for assessing material reuse or recycling possibilities.

Designing newer buildings for reuse, especially through modular design and steel construction methods, can aid in resource conservation (World Steel Association, 2021). This approach recommends incorporating demountable connections such as screws and bolts, enabling buildings to be easily repurposed as community needs evolve, benefiting builders, building owners, and steelmakers alike. One of the problems identified from the review was the design needs for future buildings and many researchers are trying to produce solutions for it.

2.4.6. CONSTRAINT FOR HIGH INITIAL COST

Research by (Smeets et al., 2019), demonstrates that the cost of reused steel is significantly lower than that of new steel, as indicated in Table below. However, the process of preparing reused steel involves additional steps such as dismantling, testing, and reconditioning, which are essential for ensuring safety and suitability for reuse. These additional steps are not seen in new steel which eventually make the initial cost for reuse steel more than the newer one. The cost difference for the reuse is not much but if the demand for the reuse of steel is higher than this small-scale difference could be much higher when purchase in larger quantity.

Table 18 - Comparison of costs for new and reused elements; Source: (Smeets et al., 2019)

Cost component		New steel beam (£/t)		Re-used steel beam (£/t)		Key actor
		Min	Max	Min	Max	
Striking down		-	-	120	165	Demolition Contractor
Steel		530	750	200	300	Stockist
	Standard operations	110	110	110	110	
	Steel cost	400	600	90	190	
	Premium uncommon sections	20	40	-	-	
Testing		-	-	145	175	Stockist
Reconditioning		-	-	100	200	Fabricator
	Shot blasting	-	-	15	55	
	Removing welds	-	-	-	25	
	Removing end plates	-	-	85	120	
Fabrication		498	700	498	700	Fabricator

	Administration	50	65	50	65	
	Design	55	80	55	80	
	Bolts/primer	25	35	25	35	
	Erection	120	165	120	165	
	Cuts/Welds/Drills/Shot blasting	248	355	248	355	
Transport & handling		20	25	65	75	Other
TOTAL		1048	1475	1128	1615	

Even though there has been a lot of progress in this topic, there are still some hurdles to overcome when it comes to reusing steel. One of the main issues is that it's often initially more expensive to use reclaimed steel. That's because it takes extra time and effort to find, test, and work with it. Moreover, sourcing challenges for suitable reclaimed steel materials limited interest in working in this area which obstructs availability of functional steel materials that meet the required specifications for various applications. Even though researchers have conducted several studies to establish better rules and systems for using old steel, most of their focus is on making designs better and more efficient, rather than concentrating on increasing the adoption rate of reuse from a minimum percentage to come closer to the recycling rate.

Another challenge is that most people tend to prefer using new steel over old steel, even though recycling old steel is better for the environment. It can be assumed that there are more countries developing, and European countries have strict rules and regulations to achieve the European Green Deal, indicating that advanced countries have full governmental support and funding. To solve this problem and create awareness in the market, one needs to find ways to make using old steel cheaper right from the start. If we can figure that out, more people might be willing to choose old steel over new.

But it's not just about money. There's also the issue of finding enough workers who know how to handle old steel properly. Sure, it might cost more to pay these workers and experts to deal with old steel, but it also creates job opportunities and builds expertise in this area, which in the long run, the demand for expertise could go down and bring a cheaper employee. Moreover, it gives us a chance to educate more people about the benefits of using old steel.

So, if one could find solutions to these challenges, then there might be more and more people choosing to use old steel. And that would not only be good for the environment, but it could also create more demand for reusing steel in the future.

3

METHODOLOGY

In this chapter, it provides a comprehensive framework for understanding the barriers to steel reuse in construction and developing actionable solutions. By leveraging extensive secondary data sources—such as academic literature, industry reports, steel industry websites, and design codes—this research aims to make a significant contribution to the field. It does so by providing evidence-based recommendations designed to address the numerous open questions that currently hinder the reuse rate of steel in the construction industry.

The framework integrates diverse perspectives and data, enabling a thorough examination of both technical and non-technical obstacles. These include regulatory challenges, economic considerations, design limitations, and logistical issues. By systematically analyzing these factors, the research not only identifies key impediments but also proposes practical strategies for overcoming them.

3.1 RESEARCH DESIGN

This study employs a qualitative research design to explore the barriers to steel reuse in the construction industry and propose solutions to enhance its adoption. The research relies heavily on a comprehensive literature review and analysis of both historical and current design codes, as well as information from steel industry websites. The approach comprehensively addresses the research objectives and answers the open questions that exist.

3.2 RESEARCH APPROACH

A comprehensive literature review was undertaken to identify and evaluate the existing barriers to steel reuse, along with potential benefits and constraints. The review comprised a diverse range of sources, including:

- Peer-reviewed research papers: These provided rigorous academic insights and empirical data on the technical, economic, and environmental aspects of steel reuse.
- Industry reports: These documents offered practical perspectives and real-world examples from the steel industry, highlighting current practices, challenges, and innovations.
- Steel industry websites: These online resources furnished up-to-date information on industry standards, technological advancements, and market trends related to steel reuse.
- Historical handbooks on design codes: These handbooks provided a historical context, tracing the evolution of design codes and practices over time, which is essential for understanding longstanding barriers.

- Current design codes: These contemporary standards were reviewed to assess current regulatory and technical requirements that influence the feasibility of steel reuse.

3.3 DATA COLLECTION METHODS

Data collection was performed through secondary data sources:

- Research Papers and Reports: An extensive collection of academic papers and industry reports was analyzed to understand the various barriers to steel reuse, as reported by previous researchers. Key databases and journals were systematically searched to ensure a comprehensive review of relevant literature.
- Historical and Current Design Codes: Comparative analysis of historical and modern design codes was conducted to assess how design requirements and regulations have evolved and their impact on steel reuse.
- Steel Industry Websites: Information from reputable steel industry websites was reviewed to gather insights on current practices, trends, and innovations in steel reuse. These websites provided valuable industry-specific data and perspectives that complemented the academic and regulatory sources.
- Fact-Checking and Validation: To validate the identified problems, the study will cross-reference claims with existing literature, and industry reports. This involves a rigorous process of fact-checking to ensure the accuracy and reliability of the stated problems.

3.4 DATA ANALYSIS TECHNIQUES

Thematic analysis was used to identify and analyze patterns within the qualitative data obtained from the literature. First, the paper was read multiple times to gain a thorough understanding. Next, highlighted important design codes to show significant features of the data relevant to the research questions. This design code was used to examine how steel structures were designed in the past and how these designs differ from current practices. These design codes were taken as a primary guide to solve several questions that hinder the reuse practices. A comprehensive comparative analysis was conducted between historical and modern design codes to pinpoint discrepancies and advancements that could impact the reuse of steel in construction. This analysis included the following key activities:

- A thorough cross-referencing of identified barriers with the specific requirements and provisions outlined in various design codes was undertaken. This step aimed to map out how design codes address the technical aspect of a structure, providing a clear understanding of regulatory expectations and constraints.
- The analysis identified significant inconsistencies between historical and modern design codes. By highlighting these differences, it became possible to understand the evolving priorities in structural engineering and material reuse, shedding light on areas where older codes may either lack sufficient guidance or impose constraints that modern standards have addressed.
- Finally, the implications of these findings were explored to determine how contemporary practices can adapt to incorporate the reuse of steel more effectively. This included proposing adjustments to current codes and identifying best practices from historical standards that could enhance sustainability in modern construction.

3.5 DEVELOPING RECOMMENDATIONS

Based on the analyzed data, recommendations were formulated to address the identified barriers and promote the reuse of steel in construction. These recommendations are aimed at guiding future designers, engineers, and policymakers on overcoming constraints and enhancing the adoption rate of reused steel.

4

FINDINGS & DISCUSSION

The construction industry must urgently focus on increasing the reuse of steel due to its significant environmental and economic benefits which were seen in the literature review earlier. Reusing steel can drastically reduce the carbon footprint of construction projects, conserve natural resources, and promote sustainable development. However, achieving higher reuse rates requires immediate and intensive efforts to address the existing challenges in the industry.

In the previous chapter of literature review, several questions were addressed by the researcher. These questions focus on the validity of the problems identified and the potential for developing solutions. Specifically, the review aims to determine whether the issues highlighted in the reuse of steel are genuinely significant and require focused attention. This critical evaluation helps to ensure that the civil engineering industry receives proper guidelines on addressing the most pressing challenges associated with increasing the reuse rate of steel in various countries.

One of the key objectives is to identify which problems related to the reuse of steel are valid and need immediate focus. By doing so, the goal is to offer practical solutions that can enhance awareness and improve the reuse rate of steel, potentially bringing it closer to the recycling rate of steel. Addressing these genuine issues can lead to better practices and policies in the industry.

4.1. THE UNITED KINGDOM AS A CASE STUDY FOR STEEL REUSE: RESEARCH, REGULATIONS, AND ECONOMIC FACTORS

In developing this thesis, the United Kingdom is chosen as an ideal case study area to source important references on the reuse of steel for several compelling reasons. As evidenced in the literature review, most studies on steel reuse are conducted in the UK, indicating a strong national interest in this topic and a commitment to developing innovative solutions and even the construction of building from metal framing is likely being steel in Great Britain. Additionally, the UK government's stringent environmental regulations, exemplified by the Climate Change Act 2008, and support from organizations like the UK Green Building Council, further promote sustainable construction methods.

Economically, the high costs of raw materials and construction in the UK create strong reasons for the reuse of steel, supported by advanced infrastructure for recycling. The UK's rich history in the steel industry and the presence of numerous aging industrial structures provide ample opportunities for material reuse. Furthermore, historic handbook for steel structure such as BS code of UK could highlight the detailed comparison of the importance of steel across different eras.

Collectively, these factors create a perfect environment for advancing the understanding and practical application of steel reuse, making the UK a compelling and strategically sound choice for this thesis. The UK's extensive research, regulatory support, economic reasons, and historical context provide a comprehensive foundation for sourcing valuable information on developing this thesis on how to govern the adoption rate of reuse of steel in many countries

4.2. UNDERSTANDING THE COSTS AND CHALLENGES OF REUSING STEEL IN CONSTRUCTION

Several researchers in the literature review chapter have stated that when implementing the reuse of steel in construction, there has been seen that there is need of high initial cost, but it's essential to analyze the factors contributing to this expense. Comparing the price of reused steel, it ranges from £150 to £200 per ton, to that of new steel, which can be between £1000 to £1500 per ton, demonstrates significant cost-saving potential. However, other considerations such as testing, sourcing, and specialized machinery add to the overall expense when reusing steel.

Firstly, testing involves critical assessments to ensure the structural integrity and quality of the reused steel, including several testing methods increasing both time and cost. There are several factors that need to be accounted for this such as how old is the structure? How many testing methods are required for thorough assessment? How frequently do these tests need to be conducted throughout the reuse process? How many samples need to be collected? Are there any regulations or industry standards that determine the testing procedures, and how do they influence the cost and timeline?

Secondly, sourcing the material post-demolition demands careful planning and coordination to salvage the steel efficiently. This may involve partnerships with demolition companies, scrapyards, or even international markets, affecting transportation costs and logistics. In addition to partnerships with demolition companies and scrapyards, are there other potential sources for obtaining reused steel? What factors determine the choice of sourcing location, such as proximity, availability, or quality of materials? Are there any legal or environmental considerations associated with sourcing materials from specific locations, and how do they affect the overall procurement strategy?

Lastly, specialized machinery tailored for dismantling and processing steel structures is necessary. Such equipment often comes at a premium compared to standard demolition machinery due to its precision and efficiency in salvaging materials intact. The investment in these specialized tools must be factored into the overall cost analysis. Apart from machinery for dismantling, what other specialized equipment is required for processing and refining reused steel? Are there technological advancements in machinery that could optimize the efficiency and cost-effectiveness of the reuse process? How do maintenance and operational costs of specialized machinery compare to those of standard demolition equipment, and what long-term implications do they have on project economics?

Additionally, factors such as labor and training should not be neglected and must know what level of expertise is needed to operate the specialized machinery and conduct the required testing procedures. Are there additional costs associated with training personnel to handle these tasks effectively? How does the availability and skill level of labor influence the overall cost and timeline of the reuse project?

On the other hand, looking at the environmental concerns one needs to know how do the methods of sourcing and processing reused steel impact the project's environmental footprint? Are there opportunities for implementing sustainable practices, such as using renewable energy sources or minimizing waste generation? Are there potential costs associated with environmental compliance or mitigation measures, and how do they factor into the overall project budget?

By addressing these questions, one can gain a comprehensive understanding of the factors influencing the initial cost and long-term viability of implementing steel reuse initiatives.

4.2.1 THE IMPORTANCE AND CHALLENGES OF TESTING REUSED STEEL IN CONSTRUCTION

Testing is crucial because it ensures the quality, safety, and reliability of products or materials. Through testing, defects, weaknesses, or deviations from standards can be identified, enabling corrections or improvements before deployment. Moreover, testing yields valuable data for making informed decisions, validating performance claims, and meeting regulatory requirements. Ultimately, testing fosters trust and confidence in products, empowering decision-makers to make informed choices without undue risk.

On the other hand, in reuse industries, the reuse of steel involves selecting the appropriate steel component based on the specific requirements of the project. Then designers or builders lists specific numbers and types of steel that are needed from the scrap or demolition industries. But the scrap yards accumulate a vast quantity of steel from various industries, including old buildings, cranes, machines, and more. Identifying the source materials within these scrap yards is challenging, making it difficult to determine how safely the steel can be reused under current load and safety standards. In the steel construction market, several guidelines direct the use of steel across different sectors such as rail, road, infrastructure, and waterways. These guidelines emphasize the properties of the steel to ensure its suitability for specific applications. Ideally, detailed information about the steel can be obtained from existing documents. However, this information is often incomplete or unclear. Additionally, structures requiring repairs may have been constructed using different types of steel, further complicating the reuse process.

This is common in structures renovated after the war with leftover materials and steels made before 1970 came from many suppliers, so their properties might differ from one to another (IWT Solutions AG, n.d.). Given the complexity of steel reuse, guidelines such as those proposed in (prEN 1090-x, 2022) recommend thorough testing of all steel components before use to ensure safety. This requirement adds another layer of complexity to the reuse industry. It might have been feasible to test or reuse steel before the 1970s, particularly during wartime when steel shortages were prevalent. The studies in literature review chapter suggests that fabricators and manufacturers faced limitations during this period, potentially simplifying steel identification processes.

Today, however, numerous steel fabricators produce a vast array of steel components, further complicating the reuse process. The purpose of ongoing studies is to streamline the adoption of steel reuse, aiming to make it more practical and widespread. Despite this goal, the standards outlined in prEN 1090-x (2022) for testing all steel materials may not always be practical or feasible to implement in every scenario.

Examining the current state of steel structures, it becomes evident that the potential for steel reuse hinges significantly on the lifespan of the building in question. Even if the construction year of a building can be identified, the initial step involves a meticulous process of sorting the steel based on its manufacturing year. To achieve this, we must first delve into the history of the steel used in the building and its properties, provided they are documented somewhere.

A significant challenge lies in determining whether any authentic historical documents exist that detail the steel's properties or the fabricators who produced it. If such documents do exist, it is crucial to verify whether the fabricators of the past employed identification marks or labels on the steel. Additionally, we need to ascertain the types of steel used historically and their specific applications, which could range from residential buildings and high-rise structures to bridges and railways.

Understanding these complicated relationships is essential as it simplifies the process of identifying the manufacturing era of steel, which is a critical step in sorting it chronologically. In cases where all the necessary information is not readily available, we need to establish an initial step to discover this data. Thus, our first task is to conduct a thorough analysis into the basic history of steel used in construction. By doing so, we can logically address and solve numerous questions that arise, ensuring a comprehensive understanding of the materials at hand.

4.2.2. FINDINGS: THE EVOLUTION AND IMPACT OF STEEL IN CONSTRUCTION

Steel production began in the 19th-century Industrial Revolution, but its history is much older. Ancient craftsmen in China and India knew how to make steel. Over 4,000 years ago, people found meteoric iron, and by 1800 BCE, India was producing smelted iron. Iron Age metalworkers likely discovered steel by accident while working with iron. Early blacksmiths used steel for tools and weapons and developed methods like quench hardening which is a method to quickly cooling the worked steel in water or oil to enhance its hardness. Today, steelmakers produce high-strength, lightweight steels that are more efficient, reduce emissions, and are recyclable. The industrialization of steel has been key in building the modern world (World Steel Association, n.d.).



Figure 10 - Iron Age metalworkers most likely stumbled upon the creation of steel unintentionally through their work; Source: (Media Store House, 2003)

In earlier times, building materials like wood and stone-faced limitations not only in terms of their strength and weight but also due to the scarcity of skilled craftsmen capable of designing and constructing sizable projects. The strength-to-weight ratios of wood and stone imposed constraints on the scale and complexity of buildings they could support. Thereover, the shortage of craftsmen proficient in these materials further hindered construction possibilities. Before 1750, most houses were predominantly constructed from wood and stone. By 1850, however, iron had risen as the preferred material for substantial structures, thanks to its superior strength and widespread availability, enabling the realization of larger and more ambitious projects.

In the early 1800s until now, the metal industries have evolved significantly. In the 1800s, three types of metals made from iron were commonly used: wrought iron, cast iron, and steel. The earliest known structures made from wrought iron mostly includes Fences, gates and railings, balconies, porches and verandas, Canopies, which are mostly seen as decorative functions.



Figure 11- Balcon d'un Immeuble Parisien

There were problems with the use of wrought iron such as chemical corrosion that can damage wrought iron in several ways: uniformly attacking the surface, creating pits, selectively damaging different parts of the metal, and causing stress corrosion cracking in previously stressed areas. Rust, the most common form, occurs when iron reacts with oxygen and moisture in the air, worsened by pollutants like carbon dioxide and sulfur compounds. Galvanic corrosion occurs when wrought iron interacts with dissimilar metals such as copper or zinc in the presence of moisture, speeding up corrosion. These processes pose a threat to the durability and structural integrity of wrought iron features and structures (GSA, n.d.).

To look at some of the structures made from cast iron are the Iron Bridge in Shropshire, which opened in 1781, was one of the first major projects made mostly from cast iron. It was considered groundbreaking at the time. However, it was designed with too much iron, which caused financial problems for its makers, especially Abraham Darby. The iron used in the bridge was not of the highest quality, and today you can see almost 80 cracks in the structure. Despite these issues, the bridge's successful completion encouraged other foundries, like Coal Brookdale, to use cast iron for building more bridges and structures later (GSA, n.d.).



Figure 12 - The Iron Bridge, Coal Brookdale, Shropshire, built in 1781, to cross the River Severn which marked the initial widespread application of cast iron for structural use.

In the evolution of metal industries, wrought iron and cast iron saw a decline in popularity after the 1850s, largely due to the rapid advancements and widespread adoption of steel production. Steel offered superior qualities such as increased strength, enhanced durability, and greater flexibility compared to both wrought iron and cast iron. This transition was facilitated by technological improvements that made steel manufacturing more cost-effective and efficient, enabling the

construction of larger and more intricate architectural marvels. Steel's superiority also extended to its resistance to corrosion, a significant advantage over wrought iron and cast iron, which were more prone to rusting. Additionally, steel could be easily shaped into various forms through modern rolling and shaping processes, whereas wrought iron and cast iron required labor-intensive forging or casting methods. These technological advantages and material properties collectively contributed to the diminishing use of wrought iron and cast iron in construction applications by the mid-19th century. As steel became more accessible and affordable, it quickly emerged as the preferred material for building construction and infrastructure development. Its widespread adoption marked a transformative era in the history of construction materials, ushering in an era of skyscrapers, bridges, and industrial facilities that were previously unthinkable with wrought iron or cast iron. This shift not only revolutionized architectural design but also played a pivotal role in shaping modern cities and their infrastructure around the world.

The growth of railroads in both Europe and America during the 19th century significantly increased the demand for iron, putting immense pressure on the iron industry. However, iron at the time was brittle and production processes were inefficient, posing challenges to meeting the escalating demand. This situation provided a strong financial incentive for metallurgists to innovate and find solutions. In the 1850s, Henry Bessemer revolutionized the industry by developing the Bessemer process, a groundbreaking method that used oxygen to significantly reduce the carbon content of iron, thereby transforming it into steel. This innovation marked a pivotal moment in the history of the steel industry, enabling mass production of steel at a previously unprecedented scale and efficiency (World Steel Association, n.d.).

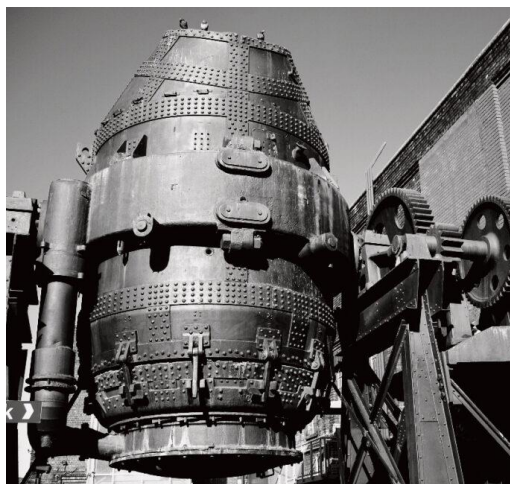


Figure 13 - The Bessemer converter developed by Henry Bessemer; Source: (World Steel Association, n.d.).

The wide benefits of structural steel in construction were seen that starting in the late 18th century, British builders implemented steel to reinforce mills against fire damage. This was followed by a milestone in 1886 with the construction of the first ever steel-framed building, the Rand-McNally building (Steel Fabrication Service, n.d.).



Figure 14 - Rand-McNally Building design by Burnham and Root architects; Source: (Steel Fabrication Service, n.d.).

As the steel industry expanded in the late 19th century, capitalists recognized its potential for substantial profits and invested heavily in production. This period witnessed tremendous growth and consolidation in Britain, where annual steel production reached approximately 30 million tons by the century's end. This rapid industrialization and technological advancement laid the foundation for the modern steel industry, playing a crucial role in shaping global economies and infrastructure. In the 20th century, particularly after World War II, steel became more widely available globally, leading to increased steel building production due to its numerous advantages over traditional materials like wood and stone. (Steel Fabrication Service, n.d.).

Following the widespread adoption of the Bessemer converter, which revolutionized steel production, significant building projects such as 60-story Woolworth Building in New York City in 1913, were set to elevate its skyline after its completion. This advancement marked a turning point in construction, demonstrating increased confidence in using steel due to its strength, flexibility, and efficiency compared to traditional building materials like wood and stone. It was also the tallest building globally that year and served as a blueprint for pioneering American steel-frame construction. This shift not only simplified construction processes but also enabled the creation of larger and more innovative structures, laying the groundwork for modern architectural achievements (Steel LLC, n.d.).



Figure 15 - The Woolworth building; NY, Source: Archdaily

Now to compare the overview at the properties of wrought iron, cast iron and steel iron, there isn't much difference in the chemical composition. It is only the difference of carbon content in each metal. But the most differential factor in construction is its strength in use in the buildings and bridges. Cast iron is molded by pouring molten metal into a mold to create intricate shapes. It's strong under compression but weak under tension, and stiffer than wood, though it can be brittle. To see their difference in detail, wrought iron is strong in both tension and compression, making it safer for beams than cast iron. It's ductile but can only be shaped by rolling or forging, limiting its structural and decorative forms. Mild steel shares properties with wrought iron but is generally stronger and can be cast or rolled. However, it's less resistant to corrosion and not as easily shaped into elegant designs (ArcelorMittal, n.d.).

Table 19 - shows these characteristics regarding strength and carbon content, but the numbers are rough estimates; Source: (ArcelorMittal, n.d.).

Material	Approx. range of carbon content (%)	Compression (N/mm ²)	Tension (N/mm ²)
Cast iron (grey)	2,25 - 4,0	400 - 1000	100 - 150
Wrought iron	0,02 - 0,05	250 - 400	250 - 400
Steel (weldable)	0,2 - 1,0	350 - 700	350 - 700

Given the current situation, steel has become highly popular in construction industries, making the reuse of wrought iron and cast iron less feasible for several reasons. One reason is the outdated codes governing the use of these materials. Additionally, steel has been proven superior to wrought iron and cast iron in various applications. Furthermore, modern infrastructure rarely incorporates cast or wrought

iron. Historically, these materials were more commonly used, but today, we need to focus on finding solutions for reusing demolition steel or steel from scrap yards. The first step in this process is identifying and distinguishing steel from wrought iron and cast iron from existing structures or from scrap yards. It is easier to understand that wrought iron is not seen much as structural element due to its weak ductile properties and cast iron was mostly used in bridge construction.

According to (ING, 2023), steel structures or reinforced steel have a lifespan of 50 to 60 years. If refurbished, they can last an additional 10 to 15 years, giving them a total lifespan of approximately 70 to 80 years. After the Bessemer converter was introduced around 1850, steel production increased significantly, reducing the production of wrought and cast iron. The first steel skyscraper was built in 1890. Using simple math, we can see that structures made from these materials would only last until 1900 to 1910 from 1850.

During the World War era, metal production increased due to advancements in steel production discovered by scientists and researchers. Steel was mainly produced to construct weapons, tanks, and vehicles. Many infrastructures were also destroyed during this time, leading to a shortage of steel and the reuse of steel and other metals. The question then arises: for what purpose was the reused metal or steel used? This question is challenging because, during wartime, the focus was on manufacturing arms, weapons, and mobility systems like vehicles and tanks.

Our studies focus on existing old infrastructure that will eventually need to be demolished or refurbished. Identifying these old buildings or structures can help future demolition contractors determine the type of steel used, simplifying their work. Another crucial factor is the scrapyard, where tons of steel from various products are found. We need to determine which scrap metal can be reused and if it is necessary to search the scrap to find usable steel, as the quantity of reclaimable steel is uncertain.

Another important scenario to consider after the war is what civil engineers would prioritize. The focus would likely be on constructing new shelters for those who lost their homes, restructuring infrastructure, and reviving destroyed cities to make living easier again. As a civil engineer, I believe this period would see significant innovations. There might be a surge in developing remarkable steel structures or inventing new solutions to make construction faster and cheaper.

The steel industry after World War II saw a significant rise in the demand for steel, leading to the production of tons of steel by several fabricators. During this era, the UK emerged as a leading country in steel production, exporting large quantities to other parts of the world, including the US. After 1950, numerous fabricators and many varieties of steel were introduced in the construction sector. This excess production made it difficult to identify steel based on its fabricator. However, with the rapid pace of development, the concept of reusing materials might have been overlooked. The massive damage to materials may have made it difficult to find reusable resources, and advancements in production might have overshadowed the reuse of steel.

Looking at the lifespan data of steel structures, one needs to consider the current year and subtract 60 to 70 years, which highlights structures built after the war, around 1954. Although many fabricators produced steel until the 1970s, the infrastructure built after 1954 is now nearing the end of its lifespan and is more prone to demolition.

4.2.3. COMPARATIVE ANALYSIS OF HISTORICAL AND MODERN STEEL CONSTRUCTION ELEMENTS FOR DEMOLITION AND REUSE

Let's examine the types of steel elements used in construction, bridges, and buildings in the past compared to today. This understanding helps demolition teams anticipate the materials they may encounter when demolishing older buildings, especially those constructed around the 1950s. Many old

buildings in countries like Germany and the UK can be identified by their construction dates, crucial information for accurately planning future demolition or development projects.

Scrapyards accumulate a variety of damaged materials from demolished buildings, bridges, and industrial sources such as equipment, machinery, tools, and spare parts. It's essential to understand the types, shapes, and sizes of structural elements required for designing modern buildings or structures, as the composition of steel found during demolitions or in scrapyards can vary widely.

Older buildings may adhere to different construction codes and often feature heavy steel beams, trusses, or reinforced concrete structures, unlike newer constructions using lighter steel and composite materials whose presence may be uncertain. Documented knowledge of historical construction methods and types of steel members used would greatly facilitate modern projects. However, accessing such information can be challenging as it may not be widely documented or freely accessible.

To simplify this complexity, modern construction should focus on identifying the types of sections or members needed, like assembling a jigsaw puzzle. Assessing the steel element's overall condition, size, and thickness and sorting it accordingly can facilitate its reuse in structural components, such as composite beams.

In current construction practices, the most common steel construction methods are steel frame structures or portal frame structures. The primary steel members used include columns, beams, and braces. These components form the skeleton of the building, providing strength, stability, and support. Steel's high strength-to-weight ratio makes it ideal for spanning large distances and supporting heavy loads, which is essential in modern building designs where open spaces and flexibility are valued. In contrast, in concrete structures, the most common use of steel is with rebars, also known as reinforcing bars. Rebars are essential for reinforcing concrete to resist tensile forces, which concrete alone cannot withstand effectively. By embedding rebars within concrete, the composite material gains enhanced tensile strength, ensuring the structural integrity and durability of concrete elements such as beams, columns, slabs, and foundations.

To further breakdown in detail on type of steel members needed in construction, let's see an example on what a structural element are needed for the steel frame residential building, which will further simplify us on how to go forward on reusing steel when we see tons of mixture of steel from a scrap yard or from the demolition of the building. The first important primary element is Beam, and as per (Steel Builders, n.d.), these elements are distinguished accordingly as below.

- W-beams, or wide flange beams, have a wide shape with a vertical center and two horizontal sides, used in construction to support wide spans and heavy loads.
- L-beams, also known as angle beams, have an L shape with two legs forming a right angle, used in construction for framing, brackets, and reinforcement.
- I-beams, or universal beams, have an I shape with a vertical center and two horizontal sides, widely used in construction for bearing heavy loads in buildings and bridges such as walls, roofs, columns, and beams in multi-story buildings.
- T-beams, or tee beams, have a T shape with a vertical stem and horizontal flanges, used in construction for strong vertical support in structures like bridges and columns.
- Channel beams are shaped like a "C" with a vertical web and two horizontal flanges. They are often used in residential construction to frame walls and provide structural support, including lintels and other necessary supports.
- HSS beam stands for "Hollow Structural Section" beam. HSS beams are steel beams that have a hollow, tubular shape rather than being solid throughout. HSS beams are used in various applications where structural integrity and weight considerations are crucial, such as in buildings, bridges, and other large structures. Additionally, their hollow surfaces make them prime for use in joining and fabrication.

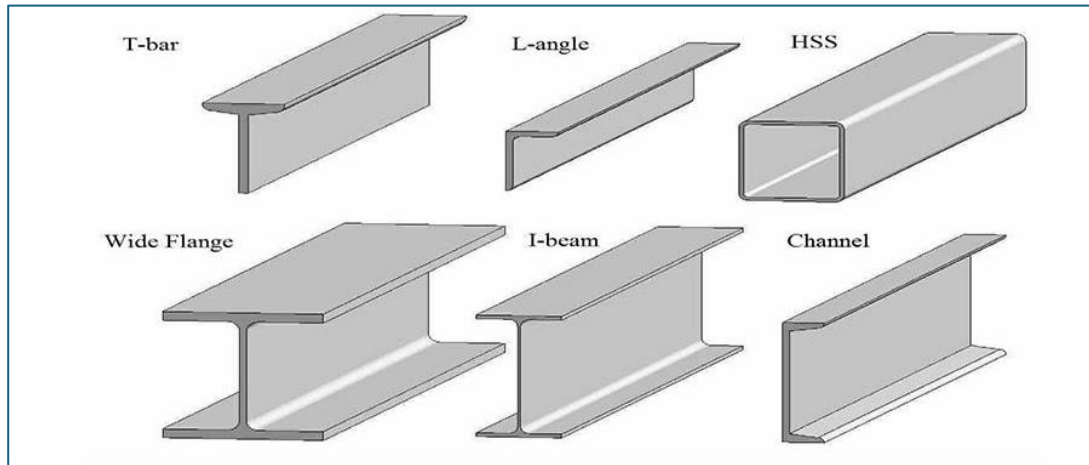


Figure 16 – Illustration on the type of beam: Source: (Ilham Agmadov, n.d.)

When investigating both minor and major details of important steel members, it is observed that, according to the (SCI, n.d.), flooring system, Wall system, Primary steel frames, Façade System and roof systems makes up the complete building structures.

First, the flooring system consists of three main types of floors, which is Floors made of light steel floor Joists, composite floor slabs and deep composite slabs.

- C section light steel joist for floors is usually between 6 and 12 inches deep. They are made of steel that's between 1/16 and 3/32 inches thick. This steel is galvanized to resist rust. Another type of floor beam, called a lattice joist, is deeper between 12 and 20 inches. These beams have space inside them for electrical wires and pipes to run through. Both types of beams are spaced close together, between 16 and 24 inches apart, to match the size of ceiling tiles and floorboards.



Figure 17 - Lightweight steel floor joists are held up by Z-shaped sections placed above load-bearing lightweight steel walls; Source (SCI, n.d.)

- Composite Floor Slab, concrete can be poured onto a wavy metal sheet. This creates a combined material that's very sturdy. The metal sheet itself is thin and only 2 to 3 inches deep.



Figure 18 - The standard composite slab and composite steel edge beams; Source (SCI, n.d.)

- Deep composite slabs are thick metal sheets that can be combined with concrete to create very strong floors that are typically 12 inches deep.



Figure 19 - Steel frame incorporating a deep composite floor, ASB beams, and infill walls integrated within; Source (SCI, n.d.)

Secondly, the wall system which consists of three main types of walls, which is wall made with load-bearing light steel framing, external infill walls in structural frames and separating walls and partitions

- Load bearing light steel framing are made from thin C-shaped metal pieces that are joined together to form flat panels. These panels are typically used in a construction method where the floors are built on top of the wall panels.



Figure 20 - Building braced light steel walls for houses using Fusion Building Systems; Source (SCI, n.d.)

- External Infill Walls, infill walls support the building's exterior and are designed to resist wind forces and support cladding weight. There are two types: individual C-section wall studs installed on-site in a bottom and top track attached to the slab and beam, and prefabricated story-high wall panels attached externally to the structure and connected to columns and floors.



Figure 21 - Installing light steel infill walls in a steel frame; Source (SCI, n.d.)

- Separating walls are internal walls that provide sound insulation and fire protection and can be either load-bearing or non-load bearing within a steel or concrete frame.



Figure 22 - Attaching plasterboard to the separating wall at X bracing; Source (SCI, n.d.)

Now most important members are the Primary Structural member which the whole structure relies on and there are four important primary member system, and they are Steel Frames with Precast Concrete Slabs, Composite Steel Frame with Composite Slabs, Integrated Beams or Slim Floor Construction and Inverted Steel Beams.

- Steel frames with Precast concrete floor slabs rest on the top flange of steel beams and can act compositely with them using pre-welded shear connectors. The top flange should be at least 190 mm wide, requiring deeper IPE/UB or HE/UC sections.



Figure 23 - Using precast concrete slabs placed on steel beams; Source (SCI, n.d.)

- Composite steel frame with Composite slabs sits on top of steel beams and works together with them using welded shear connectors through the decking. This setup is common in construction, including residential buildings with shorter spans (5 to 9 meters), and it greatly boosts the beams' strength and stiffness against bending.



Figure 24 - Steel decking and cellular beams that are composite; Source (SCI, n.d.)

- Integrated beams, also known as slim floor beams, support precast or deep composite slabs, keeping both the beam and slab at the same depth. They come in different forms: HE or UC sections with a welded bottom plate, IPE sections cut and welded to a bottom flange plate, rolled ASB beams with asymmetric shapes, and RHS beams with a welded bottom plate, often used for edge beams.

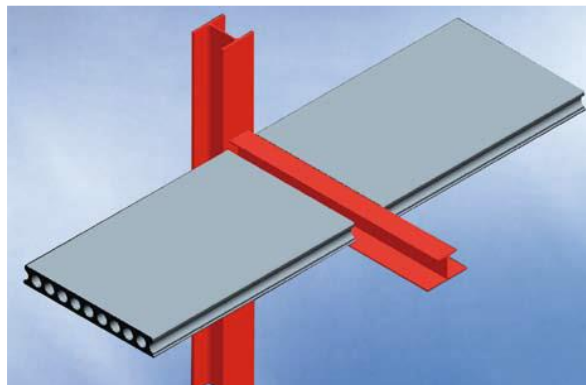


Figure 25 - Integrated floor beams that provide support for precast concrete slabs; Source (SCI, n.d.)

- The Slimline system uses inverted steel beams made from IPE sections embedded in a concrete slab, which forms the underside of the floor. These beams are spaced 600 mm apart, providing room for services above the slab. The upper floor can be covered with floorboards or a thin composite slab.



Figure 26 - Inverted Beam; Source (SCI, n.d.)

Finally, the most widely used steel materials are for façade and roof system. There are two main types of cladding suitable for the external wall systems which are, cladding that sits on the ground or floor, like brickwork, and lightweight cladding that is supported by the light steel wall.

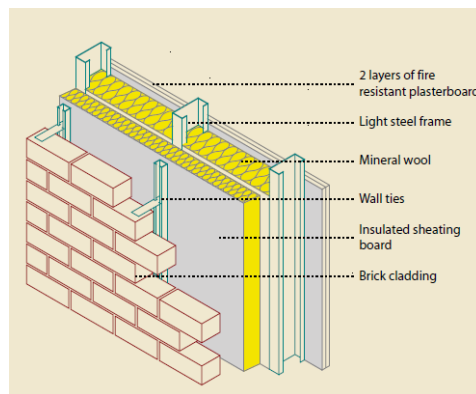


Figure 27 - An external wall with bricks attached to a light steel frame; Source (SCI, n.d.)

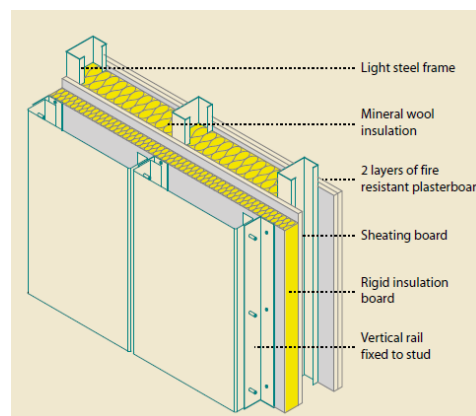


Figure 28 - An external wall with metal cladding fixed to a light steel frame; Source (SCI, n.d.)

On the other, there are several roof options available with steel construction, including steel purlins between structural frames or cross walls, an 'open roof' system for creating usable space, prefabricated steel roof cassettes, and composite panels suitable for spans up to 6 meters.

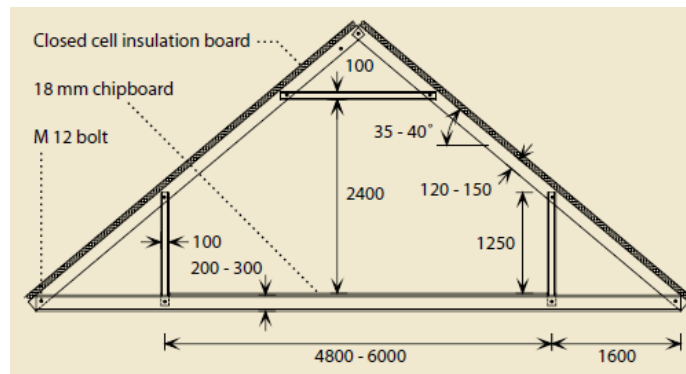


Figure 29 - An open roof system employing lightweight steel C sections; Source (SCI, n.d.)

According to (Steel Fabrication Services, n.d.), angled sections, flat sections, and custom steel sections are among the most used sections in construction, showcasing the versatility of steel in various applications.



Figure 30 – Angled Section; Source: (Steel Fabrication Services, n.d.)

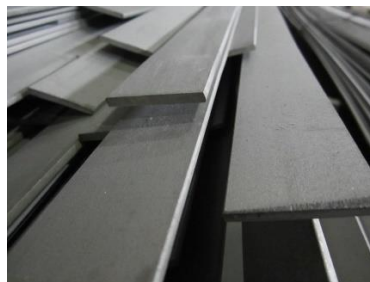


Figure 31 – Flat Section; Source: (Steel Fabrication Services, n.d.)



Figure 32 – Custom Section; Source: (Steel Fabrication Services, n.d.)

Now, with a clear understanding of the potential uses of steel products mentioned earlier, one can begin considering how to reuse steel effectively. The first step, identifying the steel used in construction from the demolition site and scrap yard, has been completed. Provisions have been established for future identification based on the specific types of members needed in modern construction. This includes evaluating whether the identified steel members can be reused and where they can function effectively. Additionally, it is important to identify buildings by their construction year. Keeping track of the construction year helps determine the materials used, which is useful when planning for demolition and potential reuse of materials. This process ensures that steel from old buildings can be effectively reused and integrated into new construction projects.

4.2.4. ASSESSING STEEL TESTING AND CODE EVOLUTION: FROM BS CODES TO EUROCODES IN REUSE PRACTICES

However, a significant question remains whether and how to test steel identified from demolition work or scrap, as recommended by the prEN 1090 code. To address this, a detailed examination of the technical aspects of reuse is necessary. Initially, it is important to identify the design codes used in the past and understand how they transitioned to the Eurocodes now commonly used in Europe. This involves examining the types of design codes previously employed, and the process by which these codes evolved and were replaced by the Eurocodes. Understanding this transition provides insight into the differences between the old and new standards, which is essential for determining the compatibility and safety of reusing old steel materials.

According to a historical handbook compiled by (W.Bates, n.d.), it was seen that BS codes historically used in the UK for designing steel structures were widely recognized and followed. Through this handbook, it was easier to understand the transition of BS code to the Eurocode which is widely used in Europe. The history of British Standards (BS) for steel structures reflects a continuous evolution to enhance safety, reliability, and efficiency in construction. Early attempts at standardization in the 1900s led to the publication of BS 15 in 1921, focusing on structural steel sections. After World War II, BS 449 was introduced in 1948 to guide the design, fabrication, and erection of steel structures. The 1970s brought more detailed standards like BS 5950, published in 1985, which provided comprehensive guidelines for steelwork in buildings.

In the early 2000s, the UK began to transition to European Standards (Eurocodes) to harmonize structural design across Europe. By 2010, BS 5950 was largely replaced by BS EN 1993 (Eurocode 3), covering various aspects of steel structure design. UK National Annexes were also developed to provide guidance specific to local conditions.

Throughout these changes, BS codes have prioritized safety and integrated new technological advancements. This continuous evolution has shaped the UK's construction practices and influenced global standards, ensuring steel structures are safe, reliable, and efficient. Let's see more details on the technical aspects, similarities and difference between the BS code and Eurocode.

According to the historical handbook for steel design by (W.Bates, n.d.) that is most commonly used in the past, uses a working stress design philosophy. This meant designing steel members to remain below a certain stress level (often a fraction of the yield strength) to ensure safety. This approach was simple but could lead to overly conservative designs, wasting material.

Over the year there were changes made in BS code, according to (BSi, 1992), the BS 5950-1:1990, looks at two types of limit states: the ultimate limit state (the point where the structure becomes unsafe) and

the serviceability limit state (the point where it no longer meets the required service criteria). Table below shows the main limit states covered in BS 5950-1.

Table 20 - Limit State; Source: (BSi, 1992)

Ultimate Limit States (ULS)	Serviceability Limit State (SLS)
Strength (yielding, rupture, buckling and forming a mechanism)	Deflection
Stability against overturning and sway stability	Vibration
Fracture due to fatigue	Wind induced oscillation
Brittle fracture	Durability

Another table below which highlights the load factor and combination when using BS code.

Table 21 – Load Factors; Source: (BSi, 1992)

Loading	Load Factor
Dead load	1.4
Dead load restraining uplift or overturning	1.0
Dead load acting with wind load and imposed load	1.2
Imposed loads	1.6
Imposed load acting with wind load	1.2
Wind load	1.4
Wind load acting with imposed load	1.2
Exceptional snow load due to drifting	1.2
Force due to temperature effects	1.2
Vertical Crane loads	1.6
Vertical Crane loads acting with horizontal loads	1.4
Horizontal crane loads	1.6
Horizontal crane loads acting with vertical	1.4
Crane load acting with the wind load	1.2

It further highlights the important material grades and their strength that were used in steel industries. The following table highlights the available steel grades, its thickness and strength that were further simplified in the year 1900s. This table further emphasizes that before 1900s, there isn't much variety and strength in steel used. Commonly used steel grades included those specified in BS 4360, such as 43, 50 and 55 which have been overtook by EN standards.

Table 22 - Design strength of different grades of steel; Source: (BSi, 1992)

BS 4360 Grade	Thickness, less than or equal to	Sections, Plates and hollow Sections
	mm	N/mm ²
43	16	275
	40	265
	63	255
	100	245
50	16	355
	40	345
	63	340
	100	325
55	16	450
	25	430
	40	415
	63	400

Then later in 2000 it is further seen the revision of BS 5950-1:2000 to make it simpler. According to (A G J Way & P R Salter, 2003), BS 5950 is a standard that includes guidelines for designing, building, and protecting steel structures from fire. It also covers material specifications, workmanship, and construction processes. This standard has several parts as follows:

- Part 1: Code of practice for design - Rolled and welded sections
- Part 2: Specification for materials, fabrication and erection - Rolled and welded sections
- Part 3: Design in composite construction - Section 3.1: Code of practice for the design of simple and continuous composite beams
- Part 4: Code of practice for design of composite slabs with profiled steel sheeting
- Part 5: Code of practice for design of cold-formed thin gauge sections
- Part 6: Code of practice for design of light gauge profiled steel sheeting
- Part 7: Specification for materials, fabrication and erection – Cold-formed sections and sheeting
- Part 8: Code of practice for fire resistant design
- Part 9: Code of practice for stressed skin design

Another important factor to be studied is the loading condition and design which is clearly mentioned in BS 6399 by (BSi, 1996). Loads were categorized based on occupancy class (e.g., offices, residential, warehouses). Typically provided minimum recommended loads for different occupancies. These values

might be conservative due to the emphasis on working stress design. It is further shown in more detail in the table below.

Table 23 – Minimum Imposed Floor Load; Source: (BSi, 1992)

Type of activity/occupancy or part of the building or structure	Examples of specific use		Uniform distributed load (kN/m ²)	Concentrated load (kN/m ²)
A. Domestic and residential activities	All uses within self-contained dwelling units including blocks of flats except as noted below		1.5	1.4
	Bedrooms and dormitories except those in hotels and motels		1.5	1.8
	Bedrooms in hotels and motels, hospital wards, toilet areas		2.0	1.8
	Billiard rooms		2.0	2.7
	Communal kitchens except in flats		3.0	4.5
	Balconies	Single Dwelling units and communal areas in blocks of flats with limited use	1.5	1.4
		Guest houses, residential clubs and communal areas in blocks of flats	Same as rooms to which they give access but with a minimum of 3.0	1.5/m run concentrated at the outer edge
		Hotels and motels	Same as rooms to which they give access but with a minimum of 4.0	1.5/m run concentrated at the outer edge
B. offices and work areas not covered elsewhere	Operating theatres, X-ray rooms, utility rooms		2.0	4.5
	Work rooms (Light industrial) without storage		2.5	1.8
	Offices for general use		2.5	2.7
	Banking halls		3.0	2.7
	Kitchen, Laundries, Laboratories		3.0	4.5

	Rooms with mainframe computers or similar equipment		3.5	4.5
	Machinery halls, circulation spaces therein		4.0	4.5
	Projection rooms		5.0	To be determined for specific use
	Factories, Workshops and similar buildings (General industrial)		5.0	4.5
	Foundries		20.0	To be determined for specific use
	Catwalks		-	1.0 at 1 m centers
	Balconies		Same as rooms to which they give access but with a minimum of 4.0	1.5/m run concentrated at the outer edge
	Fly Galleries		4.5 kN/m run distributed uniformly over width	-
	Ladders		-	1.5 run load
C. Area where people may congregate C1 Areas with tables	Public, institutional and communal dining rooms and lounges, cafes and restaurants		2.0	2.7
	Reading rooms with no book storage		2.5	4.5
	Classrooms		3.0	2.7
C2 Areas with fixed seats	Assembly areas with fixed seating		4.0	3.6
	Places of worship		3.0	2.7
C3 Areas without obstacles for moving people	Corridors, hallways, aisles, stairs, landings, etc. in institutional type buildings (not subject to crowds or wheeled vehicles), hostels,	Corridors, hallways, aisles, etc.	3.0	4.5
		Stairs and landings	3.0	4.0

	guest houses, residential clubs, and communal areas in blocks of flats not covered.			
	Corridors, hallways, aisles, stairs, landings etc in all other buildings including hotels and motels and institutional buildings	Corridors, hallways, aisles, etc. (foot traffic only)	4.0	4.5
		Corridors, hallways, aisles, etc, subject to wheeled vehicles, trolleys, etc..	5.0	4.5
		Stairs and landing (Foot traffic only)	4.0	4.0
	Industrial walkways (Light Duty)		3.0	4.5
	Industrial walkways (General Duty)		5.0	4.5
	Industrial walkways (Heavy Duty)		7.5	4.5
	Museum floors and art galleries for exhibition purposes		4.0	4.5
	Balconies (Except as specified in A)		Same as rooms to which they give access but with a minimum of 4.0	1.5/m run concentrated at the outer edge
	Fly Galleries		4.5 kN/m run distributed uniformly over width	-
	C4 Areas with possible physical activities	Dance halls and studios, gymnasias, stages	5.0	3.6
		Drill halls and drill rooms	5.0	9.0
C5 Areas susceptible to overcrowding	Assembly areas without fixed seating, concert halls, bars, places of worship and grandstands		5.0	3.6
	Stages in public assembly areas		7.5	4.5
D Shopping Areas	Shop floors for the sale and display of merchandise		4.0	3.6

Warehousing and Storage Areas. Areas subject to accumulation of goods. Areas for equipment and plant.	General areas for static equipment not specified elsewhere (Institutional and public buildings)	2	1.8
	Reading rooms with book storage, e.g. libraries	4.0	4.5
	General storage other than those specified	2.4 for each metre of storage height	7
	File rooms, filing and storage space (offices)	5.0	4.5
	Stack rooms (books)	2.4 for each metre in storage height but with a minimum of 6.5	7.0
	Paper storage for printing plants and stationery stores	4.0 for each metre of storage height	9.0
	Dense mobile stacking (books) on mobile trolleys, in public and institutional buildings	4.8 for each metre of storage height but with a minimum of 9.6	7.0
	Dense mobile stacking (books) on mobile trucks, in warehouses	4.8 for each metre of storage height but with a minimum of 15.0	7.0
	General areas for static equipment not specified elsewhere (Institutional and public buildings)	2.0	1.8
	Cold storage	5.0 for each metre of storage height but with a minimum of 15.0	9.0
	Plant rooms, boiler rooms, fan rooms, etc., including weight of machinery	7.5	4.5
	Ladders	-	1.5 rung load
F	Parking for cars, light vans, etc. not exceeding 2500 kg gross mass, including garages, driveways, and ramps	2.5	9

G	Vehicles exceeding 2500 kg. Driveways, ramps, repair workshops, footpaths with vehicle access, and car parking	To be determined for specific use
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Table 24 - The loading conditions of Euro code 1; Source: (CEN, 2002)

Category	Specific Use	Example
A	Areas for domestic and residential activities	Rooms in residential buildings and houses; bedrooms and wards in hospitals; bedrooms in hotels and hostels, kitchens and toilets.
B	Office areas	
C	Areas where people may congregate (except for areas defined under category A, B, and D)	C1: Areas with tables, etc. e.g. areas in schools, cafés, restaurants, dining halls, reading rooms, receptions.
		C2: Areas with fixed seats, e.g. areas in churches, theatres or cinemas, conference rooms, lecture halls, assembly halls, waiting rooms, railway waiting rooms.
		C3: Areas without obstacles for moving people, e.g. areas in museums, exhibition rooms, etc. and access areas in public and administration buildings, hotels, hospitals, railway station forecourts.
		C4: Areas with possible physical activities, e.g., dance halls, gymnastic rooms, stages.
		C5: Areas susceptible to large crowds, e.g., in buildings for public events like concert halls, sports halls including stands, terraces and access areas, and railway platforms.
D	Shopping areas	D1: Areas in general retail shops
		D2: Areas in department stores

Table 25 - Floor Load using Eurocode 1; Source: (CEN, 2002)

Categories of Loaded Areas	qk (kN/m ²)	Qk (kN)
Category A		
Floors	1.5 to 2.0	2.0 to 3.0
Stairs	2.0 to 4.0	2.0 to 4.0
Balconies	2.5 to 4.0	2.0 to 3.0

Category B	2.0 to 3.0	1.5 to 4.5
Category C		
C1	2.0 to 3.0	3.0 to 4.0
C2	3.0 to 4.0	2.5 to 7.0 (4.0)
C3	3.0 to 5.0	4.0 to 7.0
C4	4.5 to 5.0	3.5 to 7.0
C5	5.0 to 7.5	3.5 to 4.5
Category D		
D1	4.0 to 5.0	3.5 to 7.0 (4.0)
D2	4.0 to 5.0	3.5 to 7.0

After thorough reading of the historical code and the current codes in practice, the following differences are seen.

Feature	Historical BS Code	Eurocode 3 (EN 1993)
Design Basis	Working Stress (Fraction of Yield Strength), later in 1900s, common ground on limit state design were considered.	Limit States (Ultimate, Serviceability, Fatigue, Fire)
Material Data Availability	Limited (Few Steel Grades)	Extensive (Multiple Grades, Detailed Properties)
Section Sizes	Imperial Units (Inches)	Metric Units (Millimeters)
Load Combinations	Simpler (Dead + Live)	More Comprehensive (Permanent, Variable, Accidental)
Design Factors	Single "Factor of Safety"	Partial Safety Factors (Material, Model, Actions)

So far, the focus has been on identifying the steel section and determining whether it requires testing. With clear information now obtained, the essential steps involve evaluating whether testing is necessary and how to identify, evaluate, and use the material safely and efficiently. Testing every material might be unfeasible and uneconomical due to resource constraints.

According to historical British Standards (BS) codes, such as BS 5950-1:1990, the types of steel grades used in the past were relatively few, with different thicknesses being specified for various applications. For example, grades such as 43, 50 and 55 were commonly used. During that period, floor loading conditions were also like that of current code practice. This discrepancy indicates that historical steel

structures were also designed to handle safer loads, which may contribute to their durability and resilience over time.

Historical data reveals that steel constructions from the past were primarily used for bridges, high-rise structures, and railway tracks. These applications demanded vigorous design methods, often employing the working stress method. This conservative design approach resulted in uneconomical sections designed to withstand more imposed load than necessary, suggesting that deterioration from loading over the years would likely not cause critical damage. Consequently, these structures have a higher margin of safety against long-term wear and tear.

4.2.5. EFFICIENT SORTING AND TESTING OF HISTORICAL STEEL FOR REUSE: FROM SCRAP YARDS TO MODERN STANDARDS

It is now clear that sections or members from the past found in scrap yards need to be sorted separately based on the type of product obtained. This step simplifies the identification of historical structural materials. Given the lifespan of steel, older materials are more likely to be found in the scrap market compared to newer materials. Provisions should be made for future demolitions by creating sorting sections in scrap yards for general building structures, high-rise structures, and bridges. This approach will further enhance the reuse of materials without extensive testing. Structural elements from bridges and high-rise structures, which were designed to withstand massive loads, can easily be repurposed for normal building structures without the need for testing. This is because both past and future designers would have used best design consideration to withstand significant loads. In terms of testing, if required, one item per group can be tested rather than every steel product. This approach ensures that the testing process remains feasible and economical.

In the past design process, it is seen that, the designer considers the load combination but not as rigorous as current design practices, therefore, for normal buildings, it seems it suffice the design standards and indicates that older structural elements can be reused safely, and in many cases, like single family housing structure or reinforcing road structure where testing may be unnecessary.

Overall, these studies helped in eliminating the need for mass sample testing, reducing costs associated with testing, developing new standards, and purchasing new equipment. Instead, investments can be made in training workers to become skilled in identifying and sorting historical materials in scrap yards. This training will facilitate the efficient reuse of old materials and promote further research and development to make these processes easier in the future.

In conclusion, testing is essential to ensure compliance with current Eurocode practices, which differ from the historical BS codes. Despite the limited variety of steel grades used in the past, most historical steel structures, including bridges, high-rise buildings, and railway tracks, were designed to handle maximum loading conditions. Therefore, almost all steel products obtained from older structures can be reused with minimal testing requirements. This reuse ensures they meet Eurocode standards for newly designed buildings such as the new structure accepts these grades of steel used in the past.

4.3. EXPLORING IDEAS ON SOLVING THE AVAILABILITY OF RIGHT CHOICE OF STEEL PRODUCT

According to (Lane & Matthew Riley, n.d.), the general population often overlooks scrap metal as a valuable commodity, frequently neglecting it during the inside of recycling. However, the scrap industry plays a vital role in the economic livelihood of many underrepresented communities worldwide. While more visible commodities are forgotten once discarded, scrap metal begins a new journey toward regaining value. In the process of creating a valuable product from scrap metal, a complex chain of

activities and actors is involved. Various brokers and stakeholders within the scrap metal industry transform discarded metals into significant commodities through recycling. At each stage, what was once considered waste is filled with new economic, social, and environmental values.

On the other hand, (Fair Salvage Co., 2019), further highlights that, in the scrap yard, steel products are everywhere. Old vehicles contribute a large amount of steel scrap. Car bodies and engine blocks are mostly made of steel and are often seen in the yard. Construction materials are another big source of steel. Steel beams, girders, and reinforcement bars from demolished buildings are common. Household appliances also add to the steel scrap pile. Items like refrigerators, washing machines, and ovens contain a lot of steel. Industrial machinery provides additional steel scrap. Old machines and tools from factories are dismantled and brought to the yard. Plumbing systems also contribute. Steel pipes and fittings from old plumbing are frequently found in the yard. Overall, vehicles, construction materials, household appliances, industrial machinery, and plumbing systems make up most of the steel scrap in the yard. This steel is collected and recycled for reuse.

Looking at the information above one can imagine a huge waste material dumped in the dumpster as shown in figure below. One significant unanswered question is the availability of material which can be enough to reuse. This issue, highlighted in the literature review as a major barrier, can be addressed through an in-depth understanding of the scrap industry's operations. By examining the connections between brokers and other actors involved in transforming the value of scrap metal and what are the majors works seen in these industries.

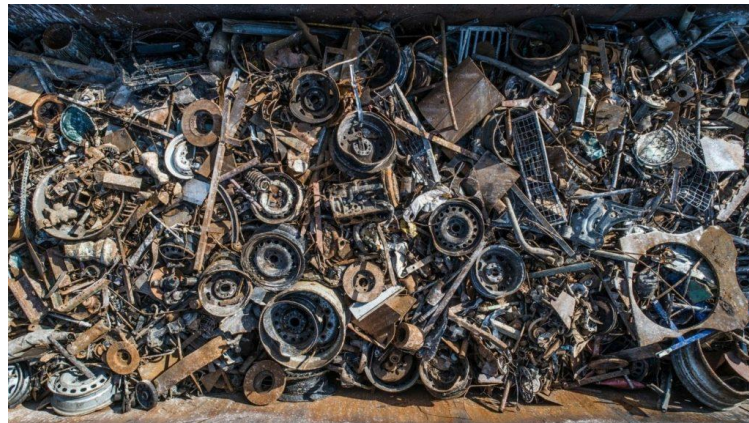


Figure 33 - Scrap Yard; source: (Anizoil, 2021)

The first and foremost question in one's mind is the function of scrap yard. According to (Fair Salvage Co., 2019), scrap yards play a crucial role in the environment by saving discarded metal from ending up in landfills. They serve as central hubs where used metal items are collected and sorted. Once sorted, the scrap metal is sold to companies that can recycle it into pure metal for making new products. Scrap yards serve as intermediaries between individuals who have small amounts of scrap metal and large businesses that require large quantities for manufacturing. Essentially, scrap yards act as brokers, gathering waste metal from various sources, sorting it, and then sending it to be refined into usable products. This process helps in reducing waste and supporting recycling efforts.

When considering the reuse of steel in construction or civil engineering industry, one critical concern is the availability of materials, as previously mentioned. A barrier highlighted in the literature is the time consumption of reused steel, when constructing new structures. While one might assume that sorting would require a time-consuming process, it is seen that these industries anyhow needed a thorough sorting of scrap metal before refining it into new products. This sorting is crucial not only for logistics but also to assess the scrap's value.

According to (Fair Salvage Co., 2019), the value of scrap metal is determined primarily by two factors. Firstly, a magnet is used to distinguish between ferrous metals (such as iron and steel, which are magnetic and less valuable) and non-ferrous metals (like copper or aluminum, which are non-magnetic and usually more valuable). Additionally, the weight of the metal pile also influences its value, with heavier piles fetching higher prices. Therefore, sorting is the initial step at the scrap yard before metals are sent for refining.

In the construction industry, specific types of steel products are required. These can be sourced from dedicated sections within scrap yards where construction and demolition waste metals are collected. To streamline the selection of materials for reuse, additional actors within these industries are needed. These actors would purchase materials from specific sources, such as demolition waste from buildings, bridges, and high-rise infrastructure. They would then sort these materials in designated sections of scrap yards, categorizing them as steel members from buildings, bridges, or high-rise structures. This organized approach ensures that the right materials are available for reuse in construction projects, and when actors from engineering industries needed these items, then they need not have to worry about the availability as well as timely consumption for sorting.

4.4. ASSESSING THE NEED FOR ADVANCED EQUIPMENT AND MACHINERY IN STEEL DISMANTLING OPERATIONS

Another significant barrier discussed in the literature is the perceived necessity for advanced machinery and equipment when considering the future reuse of steel members from existing structures during dismantling. This requirement can significantly impact the economic feasibility of purchasing and utilizing such equipment, often discouraging organizations from opting for steel reuse due to the complexities involved.

Moreover, the operation of advanced machinery demands skilled personnel, and the initial investment in these technologies and training can add substantial costs. This financial consideration, linked with the unfamiliarity and potential challenges associated with new equipment, contributes to a general reluctance to adoption of reuse practices.

However, the crucial question remains: is advanced machinery truly essential for effective steel reclaiming? To gain a deeper understanding of this issue, it is essential to delve into the specifics of the demolition and dismantling processes. By examining these processes closely, one can better assess whether the perceived need for advanced equipment aligns with practical requirements and explore alternative approaches that might streamline steel reuse efforts while minimizing costs and operational complexities.

- According to (Rabbit Demolition, 2022), one of the demolition companies explains, type of demolition given in the form services based on user preference. These companies provide several services, some of which align closely with studies focused on determining whether there is a need to invest in advanced machinery and equipment. These services include:
- Interior demolition services: which focus on dismantling the interior elements of a building while keeping the exterior intact, typically in readiness for renovation. This process can encompass the removal of walls, ceilings, plumbing, and other internal structures. By carefully dismantling these components, interior demolition allows for a thorough transformation of the space without compromising the building's outer shell. This approach is essential in urban settings where preserving the architectural facade is crucial for aesthetic and historical reasons.
- A selective demolition: A project needs careful removal of designated interior or exterior sections of a building while safeguarding the integrity of the remaining structure and surrounding areas. This method allows for precise deconstruction, ensuring that only the

targeted areas are affected, thereby minimizing disruption and damage to the rest of the building and its environment. Selective demolition is particularly valuable in projects where preservation of historical or architectural features is essential, or where only a portion of the building needs updating or repurposing. This approach also enables better control over waste management, as materials can be sorted and recycled more effectively, contributing to more sustainable construction practices

- Dismantling or deconstruction: It involves the detailed disassembly of a structure to preserve its components for reuse, recycling, or refurbishment. This method is typically more labor-intensive than standard demolition due to the careful effort required to ensure that materials remain intact and undamaged. This approach supports the preservation of significant components such as structural or architectural elements used, allowing them to be integrated into new projects or restorations.
- Total demolition: It involves the complete destruction of an entire structure, which can be carried out using various methods. This process is straightforward and entails bringing down the whole building, leaving a clear site for new construction or other uses. Total demolition is often necessary for outdated, unsafe, or unwanted buildings, making way for new development and urban renewal.
- Mechanical Demolition: This type of demolition service is executed by specialized companies using advanced mechanical equipment and tools. Hydraulic excavators with specific attachments can break down concrete and steel, effectively. These tools ensure precise and efficient dismantling, enhancing both safety and effectiveness. The use of such specialized machinery not only accelerates the demolition process but also minimizes the risk by reducing manual labor in dangerous conditions
- Implosion: A highly specialized type of demolition uses explosives to bring down tall structures by weakening their structural supports, causing them to collapse within their own footprint or along a predetermined path. Despite its rarity, implosion is particularly useful for safely and efficiently demolishing large buildings in densely populated areas, ensuring minimal impact on surrounding structures and environments.

To conclude, in the current market, the demolition of any structure is typically handled by specialized demolition teams rather than by individuals. This necessity arises due to the advanced machinery and equipment required for the demolition process, which are highlighted as barriers in the literature review due to their high costs. Despite these expenses, demolition or refurbishment becomes inevitable for any building nearing the end of its lifespan, whether the structure is safe or not.

Individuals must pay demolition companies to perform this work, as these companies follow a set of procedures and protocols. These protocols include employing skilled workers, providing proper training, and utilizing specialized equipment and machinery, especially in situations where demolition is too risky to conduct manually. While the cost of these services may vary, the expense is unavoidable for structures nearing the end of their usefulness.

Our goal is to preserve valuable materials from old structures and find ways to reuse them, rather than sending them for recycling, which is a more time-consuming process. In our studies, the type of service that closely aligns with our needs is selective demolition, dismantling, or deconstruction. These services can be considered when hiring demolition companies.

Once materials are sorted at the source, understanding and adopting reuse concepts become more manageable. This approach addresses the availability of reclaimed materials and simplifies the sorting process, which would otherwise occur at a scrapyard where the risk of damaging materials is higher. Although these services might be slightly more expensive, establishing a higher price benchmark can help recover expenses and encourage future contractors or builders to adopt these practices.

Furthermore, raising awareness starting from the scrapyards is crucial to improving future reuse adoption. This awareness will promote better sorting and preservation practices, ensuring that valuable materials are not damaged and are more readily available for reuse.

4.5. PROMOTING & ADVANCING STEEL REUSE IN CONSTRUCTION: STRATEGIES, POLICY GAPS, AND OPPORTUNITIES FOR SUSTAINABLE DEVELOPMENT

The construction industry widely embraces recycling, with steel being a notable example. Over 90% of steel is recycled globally. However, the reuse of steel lags, and in some countries, there is no data or information available on steel reuse. The market is saturated with information on recycling, but many questions remain about the reuse of steel despite its significant environmental benefits. When a researcher makes a breakthrough in solving a major medical problem, the news spreads rapidly and garners extensive media coverage, raising public awareness. Similarly, recycling was once viewed as the ultimate solution for managing used materials. Now, as challenges in recycling become apparent, researchers are exploring reuse as a potential answer. Some European governments and funding bodies are showing interest in this topic. A notable example is the recently completed project called PROGRESS. This raises questions about why other countries are not investigating reuse rates or, if they are, why there is no available information on their efforts.

To explore ways to increase the reuse of steel, it's essential to understand the significance of the scrap market. Why is the scrap market so crucial? What drives the high import and export rates of scrap? How does the cost of scrap influence decision-making? Additionally, how can governmental involvement accelerate the reuse rate while maintaining demand in the recycling and scrap markets? What strategies can enhance the adoption rate of steel reuse without compromising the scrap market's viability?

The scrap market plays a crucial role because scrap metal holds substantial economic value. Metals from various sectors—such as manufacturing, construction, and transportation—can be directly sent to recycling mills. The literature review indicates that recycling is an essential global solution to resource depletion, with up to 90% of waste metal being recyclable into new products. Recycling is well-established and operates as a major industry, so scrap metal is collected and valued based on its weight, often without requiring additional marketing efforts. Despite these advantages, the reuse of steel remains relatively niche within the broader metal industry. While reusing steel in construction offers significant environmental and economic benefits, its adoption is still limited. To enhance the reuse of steel in construction, it is important to focus specifically on this application rather than the general metal industry. Strategic planning is necessary to overcome these challenges. One effective strategy is to increase awareness and promote adoption through government policies and frameworks.

When addressing the global issue of steel reuse, several key questions arise that need to be answered before government bodies intervene. First, what specific regulations could streamline the testing and certification process for reused steel to make it more cost-effective? Additionally, how might changes in building codes and industry standards facilitate the broader acceptance and use of reused steel in construction projects?

Governments also need to consider how to highlight the environmental benefits of reusing steel to shift both public and industry perceptions. What role can government-funded research and development play in advancing technology and methods for testing and reusing steel? How might partnerships between government, industry, and academia accelerate innovation?

Furthermore, how can government policies support the development of specialized skills and training programs for workers in the steel reuse sector? What infrastructure investments are necessary to support the collection, testing, and distribution of reused steel, and how can governments foster a robust supply chain?

Finally, how can these policies and regulations encourage contractors to take an interest in steel reuse? Addressing these questions will help create a more effective framework for promoting and implementing steel reuse in construction. Furthermore, what lessons can be learned from regions or countries with successful steel reuse programs, and how can these insights be applied elsewhere? Why is there a lack of information or data on steel reuse in some countries, and what steps can be taken to improve data collection and distribution? How can educational campaigns influence the adoption of reused steel in both residential and commercial construction? Finally, what are the potential economic advantages of a higher steel reuse rate, and how can governments quantify and promote these benefits?

Many of the concerns mentioned have already been addressed. For instance, ongoing government efforts are focused on developing widely applicable codes for testing reused steel. In terms of training and skill development, the demolition industry already provides skill-building programs for workers. Additionally, specialized machinery and equipment are managed by technically knowledgeable professionals. Some countries have also funded research on this topic, and various government initiatives are underway. Researchers are working on creating easier methods for data collection and future integration. The scrap industry also plays a significant role, addressing many unanswered questions related to collection, sorting, and distribution. However, a major challenge remains: the perception that steel reuse is a complicated process. This study aims to demonstrate that steel reuse is not as complex as it may seem. To address this, there is a need for increased promotion and awareness. Governments should reach out to researchers, contractors, builders, engineers, and architects to foster a better understanding of steel reuse.

To enhance the economic viability of steel reuse, introducing financial incentives or subsidies, such as tax benefits, could be effective. Further exploration is needed to identify the most impactful support mechanisms. Additionally, the swift implementation of regulations under development, including those related to testing and updating building codes, could facilitate the adoption of reused steel.

Government campaigns that emphasize the environmental and economic benefits of steel reuse can shift public and industry perceptions, making it a more attractive option. Expanding research and development efforts, currently limited to a few countries, through global government-funded initiatives could advance technologies and methods for steel reuse. Partnerships between governments, industries, and academic institutions would further accelerate innovation.

Policies should also focus on developing specialized training programs and setting nationwide standards to address the skills gap in the steel reuse industry. Government support in this area can benefit private entities working in steel reuse. Investments in infrastructure for the collection, testing, and distribution of reused steel, as well as efforts to build a robust supply chain, are essential.

Fostering collaboration among steel manufacturers, recyclers, and reuse businesses can optimize the value chain. This might involve partnerships, joint ventures, or information-sharing initiatives to enhance the flow of materials across different stages of the lifecycle. Emphasizing circular economy principles—where materials are reused and recycled to maximize value and minimize waste—could be supported through educational campaigns, industry initiatives, and policy frameworks.

Supporting scrap industries in diversifying their offerings can help them remain competitive. Providing training, resources, or funding to develop new products or services aligned with market trends is crucial. Allocating resources to improve the efficiency and cost-effectiveness of steel reuse and recycling processes can lead to technological innovations that make reuse more attractive and enhance recycling viability. Monitoring market dynamics and industry trends will help identify challenges and opportunities. Adjusting policies, incentives, or support mechanisms as needed will ensure that the goals of promoting steel reuse and maintaining economic balance are met. Finally, leveraging successful case studies and international examples can guide policy development, ensuring a comprehensive approach to increasing steel reuse in construction.

5

RECOMMENDATIONS

While conducting this thesis, several significant findings emerged, challenging various barriers previously noted by other researchers. This research sought to simplify the identification process for reclaiming materials by focusing on the historical usage and properties of materials. By understanding the potential materials and grades used historically in the steel construction industry, one can better appreciate the evolution of materials and design codes, highlighting the critical role of the metal industry in construction and the specific methods employed in design.

The research aimed to address barriers to the reuse rate of steel by examining existing literature, fact-checking prior research, and exploring solutions to overcome these barriers, thereby enhancing the future adoption of reclaimed steel. The investigation spanned from the historical evolution of materials to the types of structural elements required in contemporary steel construction, emphasizing the potential reuse of reclaimed steel based on actual construction needs.

A significant finding of this study was the identification of constraints regarding material testing to ensure structural safety. It was concluded that not all materials need exhaustive testing; testing one or two representative groups could suffice, thereby simplifying the process. This approach can substantially reduce the economic barriers associated with extensive material testing.

Furthermore, the research explored various strategies to lower economic barriers, such as reducing the number of tests required, optimizing sorting processes, and identifying cost-effective alternatives to specialized machinery. Simplifying the complexity of reusing steel was another key focus, aiming to make the process more accessible.

Additionally, the study highlighted the necessity of creating a regulatory framework supported by the government to raise awareness and promote the reuse of reclaimed steel, which would further increase its adoption rate.

For the future work, several steps need to be undertaken to build on this research. First, there is a need for comprehensive studies on existing government regulations affecting the steel industry, including those related to the scrap industry and taxation policies. Understanding these regulations will help identify potential changes or amendments to facilitate broader adoption of reclaimed steel.

Second, the theoretical findings need to be applied in practical scenarios to evaluate the feasibility of identifying and sorting reclaimed materials and testing their suitability for reuse. This step will involve detailed exploration of technical and design data and codes to ensure safety and identify appropriate construction infrastructures for the use of reclaimed materials.

Finally, further research should focus on studying existing testing manuals and developing studies to further enhance the usage of the manual. This manual would provide standardized procedures, ensuring reliability and safety in the reuse of steel, thereby supporting the construction industry by making usage simpler.

This thesis has laid the groundwork for enhancing the reuse of reclaimed steel by addressing key barriers and proposing practical solutions. Future research and regulatory support will be essential to realize the full potential of reclaimed steel in construction, contributing to more sustainable industry practices.

6

CONCLUSION

This study has highlighted the significant benefits of reusing steel in construction, particularly in terms of resource conservation, environmental impact, and economic advantages. Despite these benefits, the practice has not been widely adopted, with reuse rates in some European countries, such as the UK, staying at just 10 to 12%. This low adoption rate contrasts mostly with the promising findings from various research studies, pointing to a gap between theoretical benefits and practical implementation.

The investigation into reuse rates in other regions, particularly Asia, revealed a lack of information on this topic. This gap suggests either a lack of awareness or interest in steel reuse or a lag in the development of advanced steel construction practices. Notably, China, a major producer and exporter of steel and scrap, lacks data on the adoption rate of steel reuse. This absence of information in such a critical region highlights the need for more comprehensive global studies and data collection efforts.

The study explored the constraints limiting the reuse rate of steel, uncovering barriers related to the complexity of work, financial costs, time constraints, and the willingness of key stakeholders like contractors, builders, and engineers. These barriers are significant but not impossible. The findings underline the need for a deeper understanding and solutions to these challenges. Overcoming these barriers requires coordinated efforts from multiple sectors, including government, industry, and academia, to create a supportive environment for steel reuse.

Additionally, the research revealed a lack of standard regulations governing the reuse of steel, posing a challenge for ensuring structural safety. Engineers and architects often focus solely on technical aspects, neglecting the broader implications of steel reuse. Establishing standardized guidelines and safety protocols could enhance confidence in reused steel, making it a more feasible option for construction projects. This regulatory framework would need to be developed with input from all stakeholders to ensure it addresses the practical concerns, safety requirements of the industry and general conditions of use, apart from technical aspects.

The study also explored the historical context of the metal industry, the types of steel used in past constructions, current design practices, and the functioning of scrap yards and demolition teams. This comprehensive approach aims to provide a clearer understanding and guide future researchers in addressing the complexities of steel reuse. By documenting the entire stage of steel and its various applications, the study offers valuable insights into potential improvements and innovations in reuse practices.

In conclusion, while this study did not determine a precise reuse rate, it suggests that the rate could increase significantly with enhanced promotion, awareness programs, and governmental support. By addressing the identified barriers and fostering a supportive environment, the construction industry can

move towards more sustainable practices. The potential for growth in steel reuse is substantial, but it will require a concerted effort to shift current mindsets and practices.

The findings of this study point out the importance of continued research and collaboration across disciplines and borders. Future research should focus on developing practical solutions to the identified barriers, establishing robust regulatory frameworks, and promoting awareness and education about the benefits of steel reuse. Additionally, there is a need for more detailed data collection and analysis to provide a clearer picture of global reuse rates and practices.

This study serves as a foundation for future research, offering insights into the history, evolution, and potential of steel reuse in construction. By building on this foundation, researchers and practitioners can work towards a more sustainable and resource-efficient construction industry. The journey towards widespread adoption of steel reuse is complex, but with dedicated effort and innovation, the environmental and economic benefits can be realized on a global scale.

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