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Exploring the Potential of Recyclable Steel in Circular Economies

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Abstract

As the global community faces the pressing challenges of environmental degradation and resource depletion, the imperative for sustainable solutions has never been more pronounced. This research introduces an in-depth exploration into the realm of recyclable materials, with a specific emphasis on steel—an essential component in various industries and a major contributor to environmental impact. The research investigates current recycling technologies and processes that facilitate the transformation of steel into a circular resource. Additionally, it explores the economic feasibility and scalability of implementing these recycling methods on a broader scale. Special attention is given to the advancements in technology that enhance the efficiency of steel recycling and the integration of circular economy principles. The research examines the role of stakeholders, including government bodies, industries, and consumers, in promoting the adoption of recyclable materials, specifically steel. It addresses the challenges and opportunities associated with fostering a sustainable mindset and creating a more circular economy.

Keywords: Recyclable material, Exploration into the realm of recyclable materials, Feasibility, and scalability, Fostering, Broader scale, Role of stake holder

INTRODUCTION

In the ever-evolving landscape of environmental consciousness, the importance of sustainable practices has become increasingly evident. One pivotal aspect of this movement is the recycling of materials, which plays a crucial role in reducing environmental impact and conserving valuable resources. Among the myriad materials that can be recycled, steel stands out as a versatile and sustainable option with a significant impact on both the economy and the environment.

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Steel, renowned for its strength, durability, and wide range of applications, is a fundamental material in our modern society. From infrastructure and transportation to packaging and household items, steel is omnipresent. However, the production of virgin steel involves considerable energy consumption and greenhouse gas emissions. Recognizing this environmental impact, the recycling of steel has emerged as a pivotal solution to mitigate the negative consequences associated with its production [1].

The process of recycling steel involves collecting discarded steel products, such as appliances, vehicles, construction materials, and packaging, and subjecting them to a systematic recovery and reprocessing procedure. Unlike many other materials, steel maintains its physical properties even after multiple recycling cycles, making it an ideal candidate for a closed-loop recycling system.

COMPARISON BEWTEN PRIMARY AND SECONDRY STEEL

Primary steel and secondary steel differ in their production processes, raw materials, and properties. Here is a comparison based on the provided sources:

1. *Production process:*
   i. Primary steel is produced using the Basic Oxygen Furnace (BOF) method, which converts iron ore into steel [2].
   ii. Secondary steel is typically made in an electric arc furnace using steel scrap as the primary raw material.
2. *Raw materials:*
   i. Primary steel is derived from iron ore, while secondary steel is produced from recycled or scrap steel.
3. *Impurities:*
   i. Primary steel has fewer impurities compared to secondary steel.
   ii. Secondary steel contains higher levels of impurities, which can affect its properties and performance.
4. *Properties:*
   i. Primary steel is known for its lower impurity content, uniform rib pattern, and higher production costs.
   ii. Secondary steel, while cheaper, may have inconsistent properties, a less refined rib pattern, and higher impurity levels (Figure 1).
5. *Cost:*
   i. Primary steel is generally more expensive due to the direct use of iron ore.
   ii. Secondary steel is more cost-effective as it is produced from scrap steel, but it may have higher impurity levels.

IMPACT IN INDUSTRY

- The steel industry has a significant impact on the environment, accounting for around 6% of total CO_2 emissions worldwide.
- However, the industry has made progress in reducing its energy consumption and greenhouse gas emissions, with steady gains in GHG efficiency.
- The recycling process of steel can also have environmental impacts, such as the use of high-voltage electric arcs to maintain the furnace at high temperatures, which requires a amount of electricity, increasing CO_2 emissions (Figure 2)
- To minimize the environmental impact of steel production and recycling, best practices such as sorting and segregation of steel scrap, using green process energy, and carbon capture and storage (CCS) techniques can be adopted [3–5].

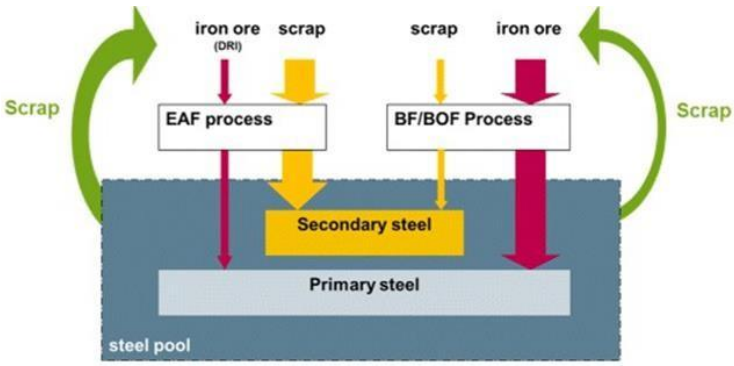

Figure 1. Compare primary and secondary steel.

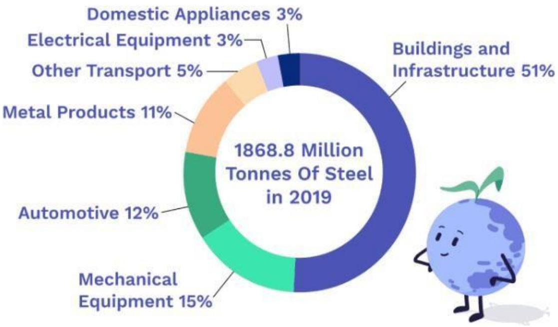

Figure 2. Steel usage cycle.

- The steel industry is also facing market decoupling, with countries implementing trade measures to protect domestic steel industries and address overcapacities.
- The industry is exploring decarbonization strategies, including the use of low-carbon hydrogen and carbon capture, utilization, and storage (CCUS) technologies.
- The adoption of innovative technologies, government investments in research and development, and a growing emphasis on sustainability are some of the prevailing trends embraced by major manufacturers in the steel industry.
- Therefore, the steel industry is actively addressing environmental concerns, exploring new opportunities, and contributing to a more sustainable future.

TECHNOLOGY ADVANCEMENT IN STEEL IN PROCESS

1. *Electric arc furnace (EAF) technology*: advancements, enabling the melting of scrap steel using electric arcs. This method is more energy-efficient compared to traditional blast furnaces.
2. *Direct reduction processes: advancement:* Technologies such as direct reduction processes, like the Madrox and HYL processes, aim to produce directly reduced iron (DRI) from iron ore without the need for coke ovens.
3. *Use of hydrogen in steel production: advancement:* The steel industry is exploring the use of hydrogen as a clean alternative to carbon-intensive processes. Hydrogen can be used as a reducing agent in the production of steel, resulting in water vapor as the only byproduct [6].
4. *Smart manufacturing and industry 4.0: advancement:* The integration of digital technologies, data analytics, and automation in steel production is part of the industry 4.0 revolution.
5. *Recycling technologies: advancement:* Advancements in recycling technologies, such as advanced sorting systems and sophisticated separation techniques, have improved the efficiency of steel recycling processes (Figure 3).

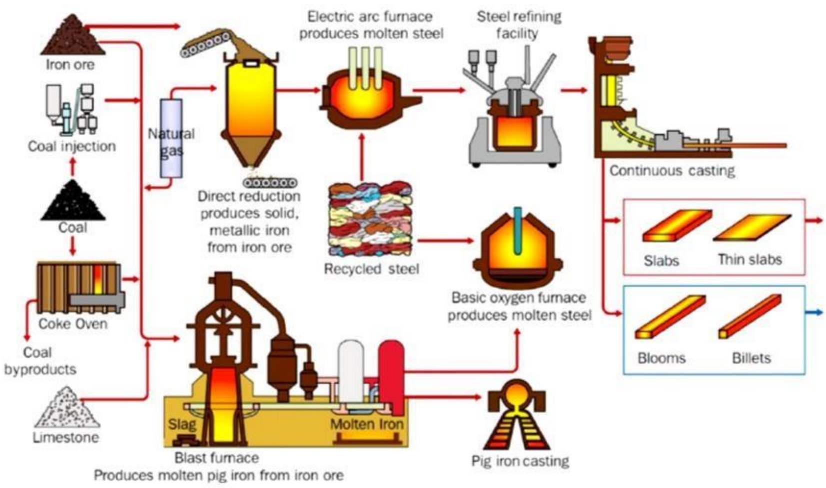

Figure 3. Steel production.

QUALITY AND PURITY OF STEEL

The quality and purity of steel are critical factors that determine its suitability for various applications. Several aspects contribute to ensuring high-quality and pure steel, including the composition, production processes, and testing methods. Here are key considerations for understanding the quality and purity of steel [7]:

1. *Chemical composition:* The chemical composition of steel, including the presence of elements such as carbon, manganese, sulfur, phosphorus, and alloying elements, determines its mechanical properties and suitability for specific applications.
2. *Steel production processes: quality aspect:* The production process significantly influences the quality of steel. Different methods, such as the basic oxygen furnace (BOF) process and the electric arc furnace (EAF) process, have varying impacts on the final product.
3. *Heat treatment: quality aspect:* Heat treatment processes, such as annealing, quenching, and tempering, are employed to achieve desired mechanical properties and enhance the quality of steel.
4. *Casting and solidification processes: quality aspect:* The casting and solidification processes impact the grain structure and overall integrity of the steel [8].
5. *Non-destructive testing (NDT): quality aspect:* Non-destructive testing methods, such as ultrasonic testing, magnetic particle inspection, and radiographic testing, are employed to assess the internal and surface integrity of steel.
6. *Quality control and certification: quality aspect:* Rigorous quality control measures, adherence to industry standards, and certifications from recognized bodies contribute to the overall quality of steel.

CONSUMER ACTIVITY TOWARDS CONSUMPTION OF STEEL

Consumer activity towards the consumption of steel is influenced by various factors, reflecting the diverse applications of steel in everyday products and infrastructure. Understanding how consumers engage with steel involves considering their preferences, perceptions, and the broader trends shaping different industries. Here are key aspects that highlight consumer activity in the consumption of steel (Figures 4 and 5):

1. *Automotive preferences: consumer activity:* Consumer choices in the automotive sector influence the demand for steel. Preferences for certain vehicle types (e.g., SUVs, trucks) impact the overall consumption of steel in the automotive industry [9].
2. *Home Construction and Appliances: consumer activity:* Consumers play a crucial role in the demand for steel in home construction and appliances. Preferences for steel-based appliances, kitchenware, and structural elements contribute to consumption.
3. *Infrastructure and building Materials: consumer activity:* Construction projects driven by consumer demand for residential and commercial spaces contribute significantly to steel consumption.

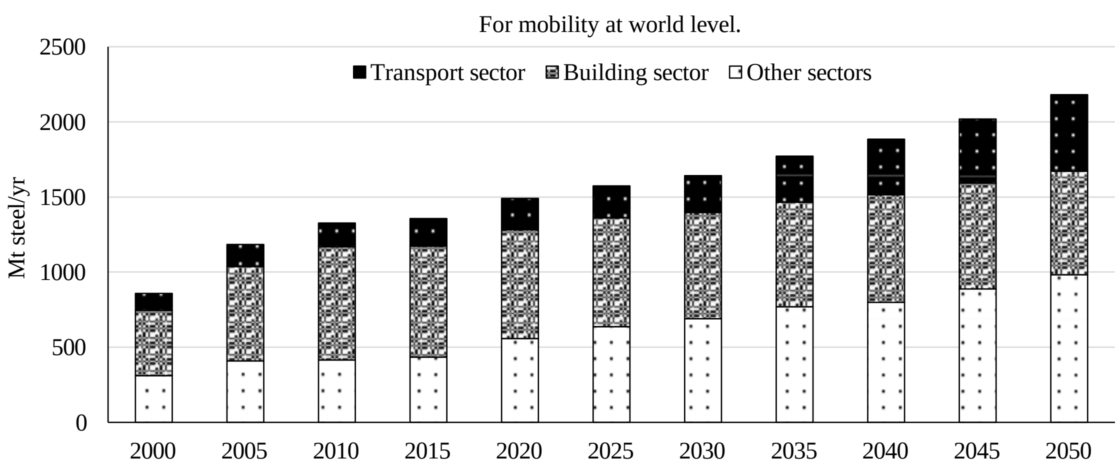

Figure 4. Graph show the mobility.

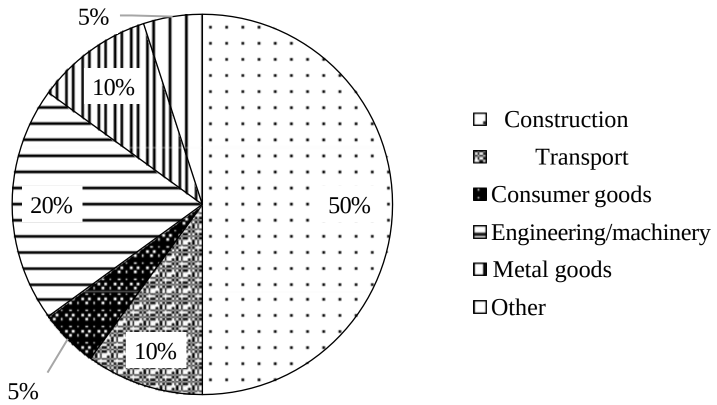

Figure 5. Pie chart.

4. *Consumer electronics: consumer activity:* Steel is used in various consumer electronics, from smartphones to laptops. Consumer choices in electronic devices impact the demand for steel in the electronics industry.
5. *Packaging and containers: consumer activity:* Steel is used in packaging, including cans and containers for food and beverages. Consumer choices in packaged goods impact the demand for steel in the packaging industry.

CIRCULAR ECONOMY IN THE STEEL INDUSTRY (PRODUCTION AND CONSUMPTION)

- The circular economy refers to a system that aims to minimize waste and promote the sustainable use of resources. Steel, as a permanent and recyclable material, plays a crucial role in the circular economy.
- Steel's high recyclability, with 85–90% of steel products being recovered and recycled at the end of their life, makes it a key player in achieving a fully circular economy.
- To advance the circular economy in the steel industry, efforts are being made to improve material and process efficiency, increase steel recycling, and adopt renewable energy sources for steel production.
- By reducing waste, driving greater resource productivity, and promoting the reuse, remanufacturing, and recycling of steel products, the steel industry contributes to the principles of the circular economy [10].
- Initiatives to design steel products efficiently, make them durable, and optimize their weight are integral to the circular economy, as they reduce the amount of material energy, and resource used to create steel products (Figure 6).

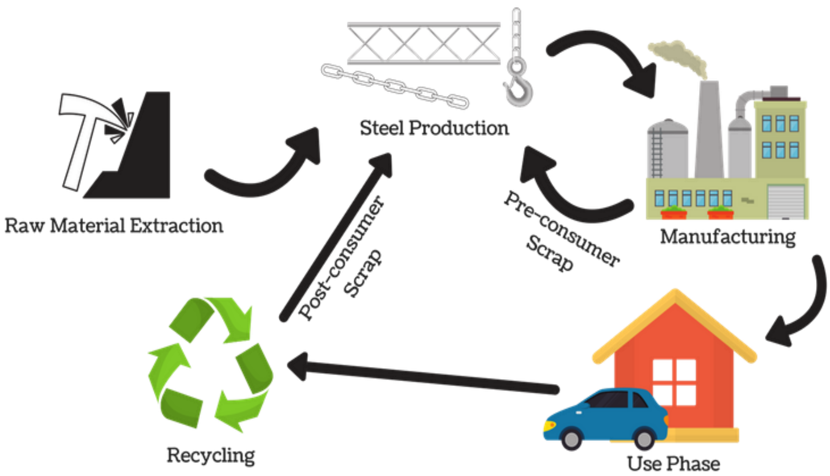

Figure 6. Steel channel.

GLOBAL PERSPECTIVE IN STEEL INDUSTRY

The global steel industry is facing a complex landscape with various challenges and opportunities. Here are some key insights from the provided sources:

1. *Global steel demand and production:*
   i. Global demand for steel is projected to increase by more than a third through to 2050, driven by economic growth, urbanization, and increased consumption of goods.
   ii. To address this, the industry is exploring decarbonization strategies, including the use of low-carbon hydrogen and carbon capture, utilization, and storage (CCUS) technologies.
2. *Circular economy and recycling:*
   i. Steel is highly recyclable, with 85–90% of steel products being recovered and recycled at the end of their life.
   ii. The industry is actively embracing the principles of the circular economy to minimize environmental impact and promote sustainable resource use.
3. *Market trends and trade dynamics:*
   i. The steel industry is experiencing market decoupling, with countries implementing trade measures to protect domestic steel industries and address overcapacities.
   ii. The industry is also facing supply chain disruptions and uncertainties, which require strategic adaptation and resilience.
4. *Long-term implications and strategic planning:*
   i. The steel industry is navigating long-term trends, including unevenly distributed slowdowns in global steel demand, regional overcapacities, and the need to strengthen raw material supply chains.
   ii. Companies are advised to update their strategies, focus on capital expenditures, and prioritize technological agility to navigate the evolving landscape (Figure 7).

Figure 7. Steel uses.

ROLE OF STEEL IN CONSTRUCTION AND INFRASTRUCTURE

- Steel plays a crucial role in construction and infrastructure projects due to its exceptional strength, durability, versatility, and sustainability. Steel is a preferred choice for large-scale infrastructure projects, including bridges, highways, skyscrapers, stadiums, and airports, due to its ability to withstand extreme weather conditions, seismic forces, and heavy loads, ensuring long- term structural stability.
- Steel is also eco-friendly, as it is recyclable and has a low carbon footprint, reducing environmental impact and contributing to a greener future.
- Steel components can be manufactured off-site and quickly assembled on- site, speeding up construction timelines, leading to cost savings, and minimizing disruption to surrounding areas.
- Steel offers design flexibility, enabling engineers to create innovative and visually appealing structures, adapting to various architectural styles, delivering both form and function.
- While initial costs may be higher compared to other materials, steel's long- term benefits, including lower maintenance and repair costs, make it a cost- effective choice over the project's lifespan.
- The global demand for steel is projected to increase by more than a third through to 2050, driven by economic growth, urbanization, and increased consumption of goods.
- Therefore, steel is a fundamental material in the construction of buildings and infrastructure, contributing to the development of safe, efficient, and durable transportation networks and urban environments (Figure 8).

ENVIROMENTAL IMPACT TO INVESTIGATE THE COLLECTION AND SOTING PROCESS OF STEEL

The collection and sorting process of steel can have environmental impacts, but the use of recycled steel can significantly reduce the environmental impact of steel production. Steel production is highly polluting, requiring large inputs of coke, which is extremely damaging to the environment. However, steel is highly recyclable, with 85–90% of steel products being recovered and recycled at the end of their life.

The recycling process of steel can also have environmental impacts, such as the use of high-voltage electric arcs to maintain the furnace at high temperatures, which requires a significant amount of electricity, increasing CO_2 emissions.

To minimize the environmental impact of steel production and recycling, best practices such as sorting and segregation of steel scrap, using green process energy, and carbon capture and storage (CCS) techniques can be adopted. Making one ton of crude primary steel with the typical blast furnace/basic oxygen method takes 1,400 kg of iron ore, 800 kg of coal, 300 kg of limestone, and 120 kg of recycled steel.

Therefore, the collection and sorting process of steel can have environmental impacts, but the use of recycled steel and the adoption of best practices can significantly reduce the environmental impact of steel production and contribute to a more sustainable future (Figure 9).

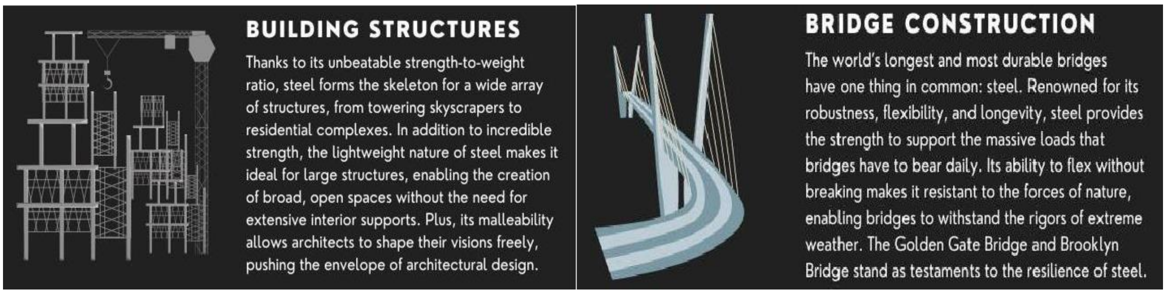

Figure 8. Building construction.

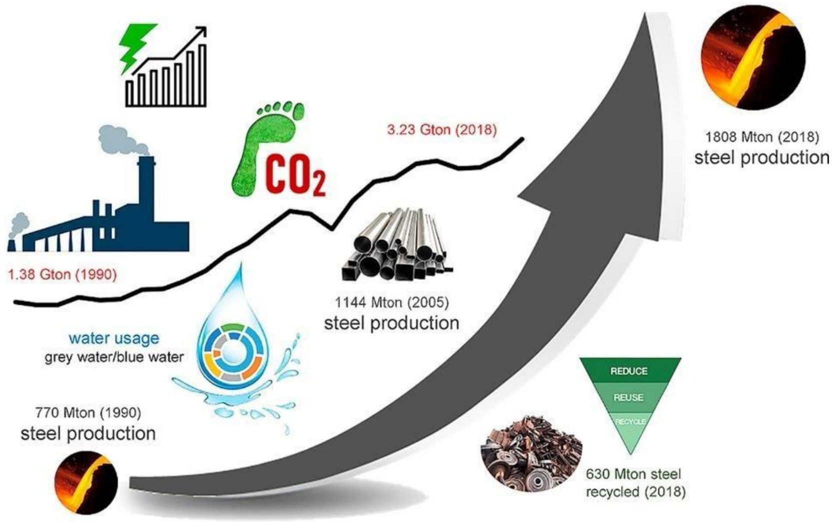

Figure 9. Enviroment impact.

COST EFFECTIVNESS STEEL V/S VIRGIN STEEL

- Recycled steel is generally cheaper than virgin steel due to the lower cost of its raw material, scrap steel, compared to iron ore, which is the main raw material for virgin steel. The production of recycled steel is also less energy- intensive than virgin steel, further reducing its cost of production. According to Statista, recycled steel costs $415 per metric ton, while virgin steel is reported to cost $920 per metric ton (Figure 10).
- The cost of reused steel is also lower than that of new steel, and reusing steel reduces the need for virgin steel, contributing to a reduction in embodied carbon.
- Therefore, both recycled and reused steel are cost-effective alternatives to virgin steel, with the added benefit of reducing environmental impact.

STEEL RECYCLED INDUSTRY ITS CHANGES AND OPPOPRTUNITY

- The steel recycling industry is experiencing significant changes and opportunities.
- The steel industry has recycled over 25 billion tons of steel since 1900, and it is easy and affordable to recover from almost any waste stream.
- The industry is focusing on integrating reuse into the economy, which presents a range of new opportunities.

Figure 10. Steel material.

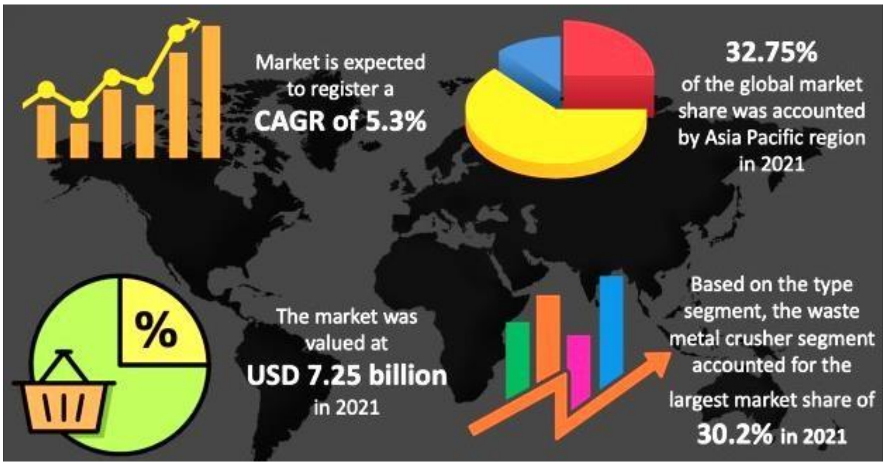

Figure 11. Table representation.

- The adoption of innovative technologies, government investments in research and development, and a growing emphasis on sustainability are some of the prevailing trends embraced by major manufacturers in the steel recycling market.
- The environmental and social benefits of creating a circular steel hub are significant, with the potential to save 60% of carbon emissions.
- The steel recycling industry is essential for a greener future, and there is a growing recognition of the potential to create an integrated and circular system of material use, particularly in the context of the energy transition and the shift towards renewable energy infrastructure.
- Therefore, the steel recycling industry is evolving to address environmental concerns, create new opportunities, and contribute to a more sustainable and circular economy (Figure 11).

LATEST INNOVATION AND TECHNOLOGY USED FOR ADVANCEMENT AND INHANCEMENT FOR STEEL RECYCLING PROCESS

1. The latest innovation and technology used for the advancement and enhancement of the steel recycling process include the following *High-tech scrap recycling:* The steel recycling industry is investing in advanced technologies to improve the recycling process. This includes the use of sophisticated methods for automatic scrap metal sorting, such as laser technologies, which offer the potential for significant cost savings at recycling plants.
2. *Alloy separation and recycling:* Innovative processes have been developed to separate and reuse alloy elements from recycled steel.
3. Sensor technology to monitor and optimize steel manufacturing processes.
4. *Circular economy initiatives:* The steel industry is actively promoting the circular economy by using scrap steel as an additional element in the steelmaking process, forming a closed-loop system where nothing is wasted. By-product recycling solutions are being implemented to convert residual production materials into useful and profitable resources (Figure 12).
5. *Heat recovery and energy efficiency:* Steel plants are adopting heat recovery systems, such as Organic Rankine Cycle (ORC) turbines, to generate energy from waste heat, reducing their environmental impact and contributing to energy efficiency.

CASE STUDY 1

The concept of combining earth and steel is based on their contrasting material properties in terms of weight, storage, compressive, tensile, fire-resistance, sustainability, and cost-effectiveness. The difference between earth and steel opens new spatial and structural possibilities, which are explored in the design of the hybrid structure as a post-Tensioned structure. The post- Tensioning concept is based on a mock-up of an after-Tensioned Earthen building developed at Sitter Werk, and the lessons learned (Figure 13).

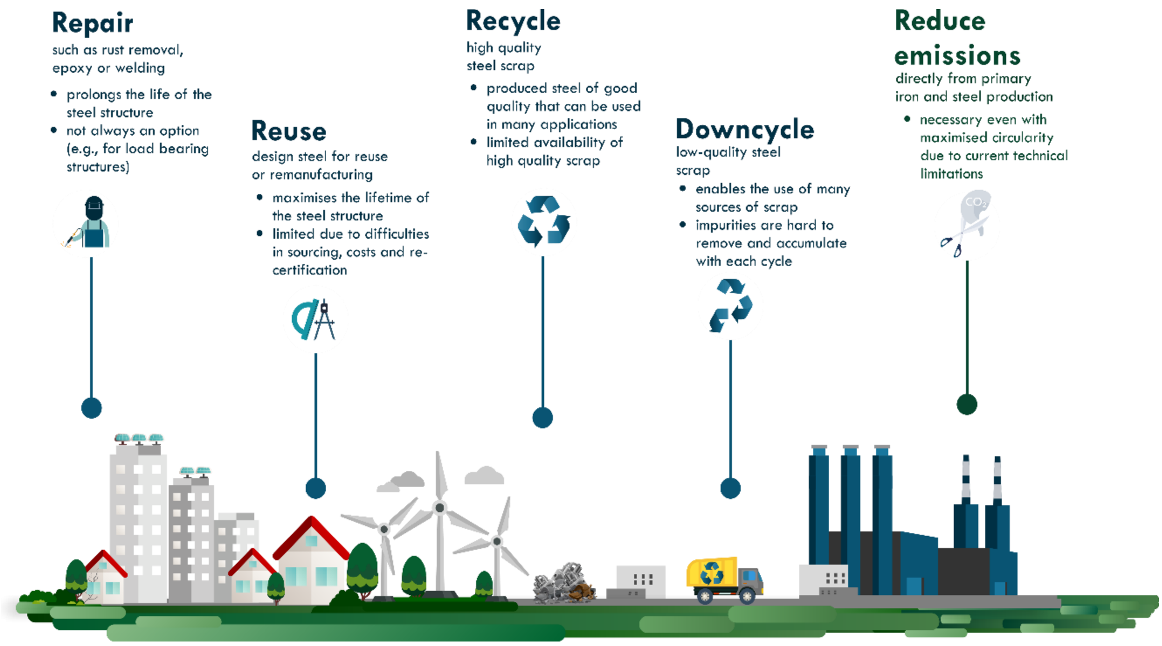

Figure 12. 5 Rs's.


Figure 13. Sitter Werk.

1. Rappers will train station will be replaced by a five-story building to address the urban and operational deficiencies in the station's square. The building's external appearance is characterized by a dialectic of earth- and steel-based structures. The linear building's ends feature two cylindrical earth-built access towers that connect the urban and public floors. The linear facades rhythmically follow programmatic and spatial considerations, while the sectional figure follows technical and programmatic considerations. The basement and the first floors, connected to the station's underpass, are used for retail and office spaces. The generous plateaus of the upper floors are used for office and commercial spaces, while the apartment entrances are located on the other side.
2. The building structure is prefabricated on the earth bulkhead building. Recycled steel beams are used in the construction of the building structure. Sheet pile section slabs are used for the building structure. The rammed earth walls need to be properly shear transferred in the horizontal joints. To do this, a vertical post tension system of steel cables is used. The steel cables can be re-tightened to compensate for settlements in the rammed earth wall. The earth walls absorb the compressive force and the steel tensile force. The sheet pile section ceilings are filled with the rammed earth on the upper side. This increases the fire resistance and structural-physical properties of the building (Figure 14).

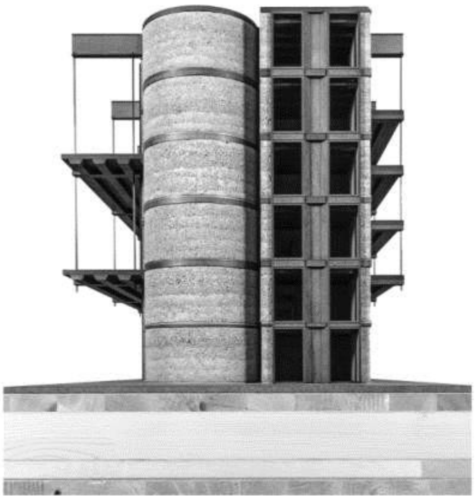

Figure 14. Sheet pile.

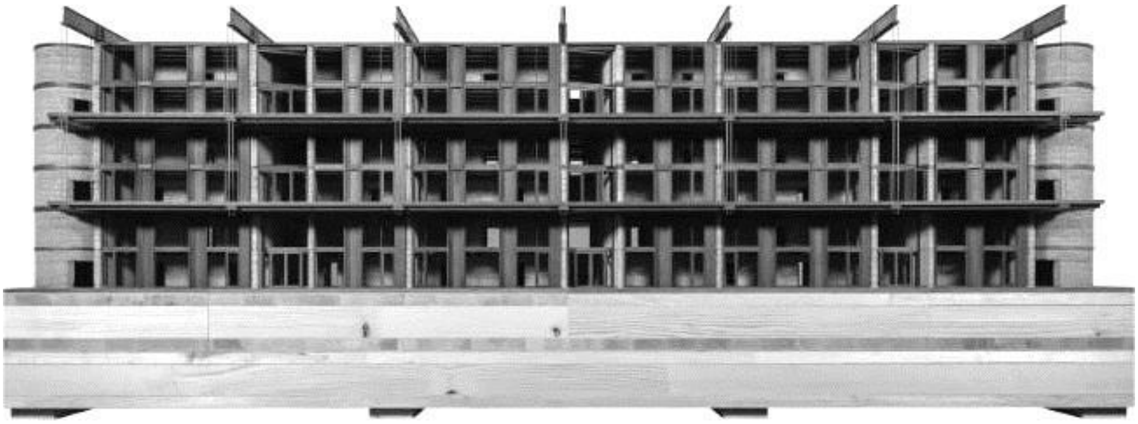

Figure 15. Heating loops.

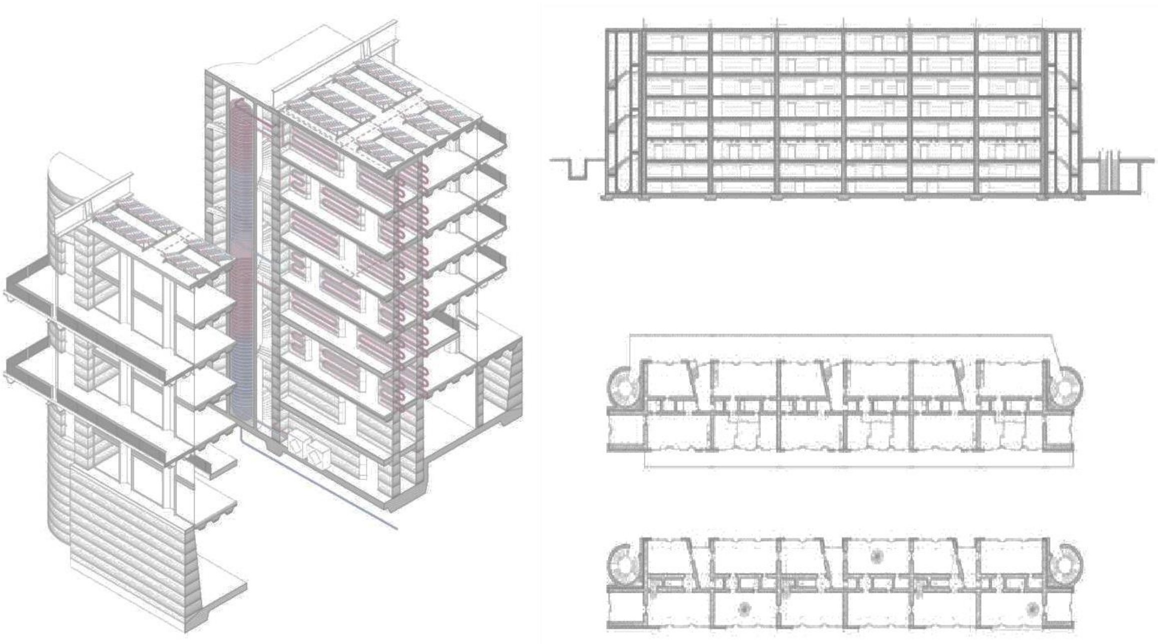

Figure 16. Storing solar energy.

Figure 17. Steel building structure in different view.

3. There is a very large storage mass in the solid earth building. This is due to the fact that the rammed earth wall is used for slow heat dissipation through the rammed heating loop. The storage capacity of solid earth walls is not only for the heating system but also for the natural control of room humidity which significantly improves user comfort. Building technology makes synergy with the earth-based building structure. The basis of the building technology is solar heat generation, which is mainly through thermal solar collectors located on the roof. The solar energy is stored in 2 large, stratified energy storage tanks of approximately 40 cubic meters, each located in cylindrical eyestalks of the staircase towers. The energy consumption is balanced on a seasonal basis and is supplemented with a renewable heating system when required.
4. The solid earth building has a very high storage mass. The rammed earth walls are used for sluggish heat dissipation via rammed heating loops. However, the storage capacity of the solid earth walls serves not only the heating system, but also the natural regulation of room humidity, which significantly increases user comfort. In this sense, the building technology makes synergistic reference to the building structure made of earth. The basis for this is predominantly solar heat generation. This takes place via thermal solar collectors on the roof and is stored in two large, stratified storage tanks of around 40 cubic meters each, which are each located in the cylindrical eyes of the stair towers. Energy consumption is seasonally balanced and is supplemented by a renewable energy heating system when needed. By storing solar energy in water tanks, a coverage rate of up to 60 percent of the total heat demand can be achieved (Figures 15–17).

CASE STUDY 2

Case Study in Modular Lightweight Steel Frame Construction

- The MUZA project, a transportable pavilion, serves as the case study for the LSF building. RMUZA is a single module that may be used as a demonstration building for NZEB systems and technologies. It is meant to be placed in public spaces and open for tours by anybody who is interested. MUZA is intended to be modular and versatile, allowing for easy adaption for various potential purposes, such as emergency housing units, permanent housing, kindergartens, schools, shopping center offices, etc.,
- Since the building must be able to be transported on all major roads using a lorry, the dimensions of a 9 m shipping container were taken into consideration during the building's design process. This was a critical need for the MUZA. This guarantees MUZA's mobility and allows it to be used in many settings with varying weather conditions. The quickness of construction and the potential to use individuals who had prior training were also significant factors. These made it clear that at least three distinct dry building methods—timber-frame, cross-laminated timber (CLT) panels, and LSF systems—are viable. Due to Croatian construction workers' incompetence in building CLT.
- Achieving the best possible indoor environment quality and minimizing energy requirements for heating and cooling was the second essential criterion for the design of the MUZA (Figure 18).

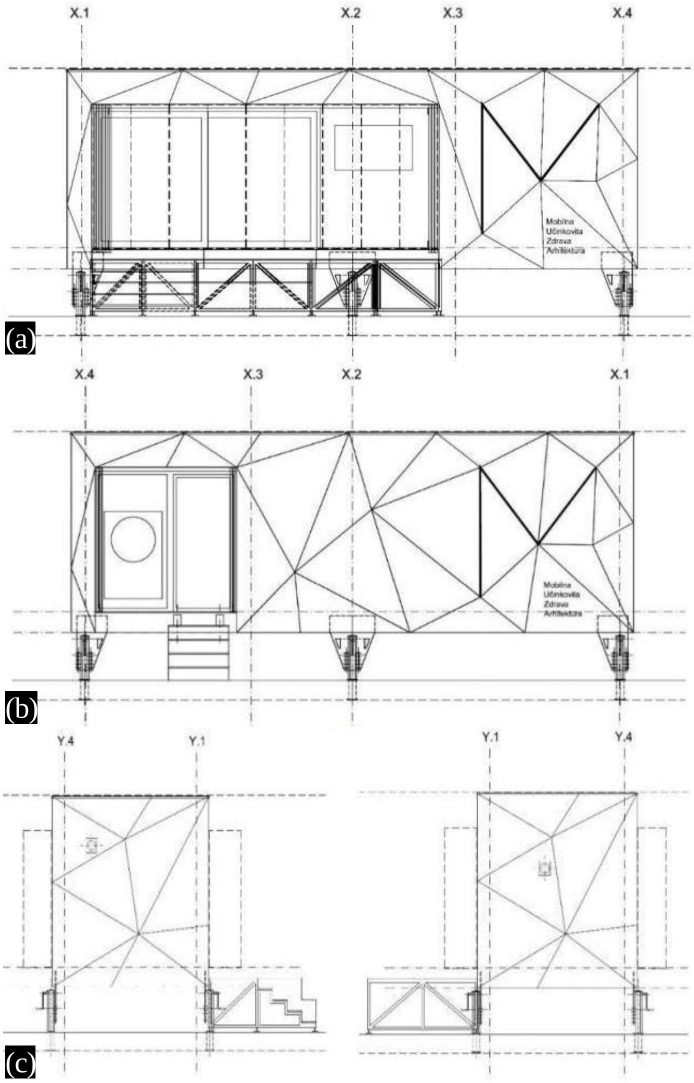

Figure 18. MUZA.

- The loadbearing structure is LSF, on which six steel sheets are welded and utilized as detachable landing gears, which are at that point utilized to exchange strengths to the ground. The divider includes a single layer of vertical steel studs each 600 mm, whereas in remarkable circumstances where extra solidifying is required, or for stack bearing purposes, the hole between two vertical studs is 300 mm. In the case of floor studs, the hole between two studs is 380 mm, whereas the hole between the roof studs is 480 mm. These distances were decided in a auxiliary examination, taking into consideration extreme restrain states and particularly serviceability constrain states, which was prevailing due to the constrain of most extreme avoidances of the coating, specialized frameworks introduced, and aesthetics (breaking of inner surfaces etc.)
- To guarantee coherence of warm cover, additional warm cover is included to both the outside and inner side of the dividers, roof, and floor. Non-combustible warm cover, such as mineral fleece, is sandwiched between vertical (divider) and even (floor and roof) steel studs. Depending on the building envelope component (filling in between steel studs, outside cover within the ventilated discuss depth, supplementary warm separator layer beneath gypsum plasterboards), diverse physical-mechanical qualities of mineral fleece cover are required (Figures 19 and 20).
- To gain an understanding of MUZA's performance in various climates and real-world scenarios, a real-time monitoring system is installed. The parameters that are monitored include energy consumption, PV panel energy production, indoor air quality parameters (temperature, relative humidity, CO_2 concentration, relative indoor air quality), and the external wall's hygrothermal performance (temperature and relative humidity in all characteristics.
- The system monitors the building's overall energy usage as well as that of the HVAC, lighting, MVHR, and ventilation systems. Using smart Wi-Fi modules, also known as power tags, energy consumption is evaluated. These modules wirelessly transfer data to the network via a gateway while continuously monitoring and measuring energy and power (current, voltage, power, power factor, and energy). The traditional automatic fuses have power tags attached to them. A logical controller, or gateway, that is mounted in the primary distribution cabinet. Monitoring is out of the scope of this paper, and the results will be analyzed and published elsewhere (Figure 21).

Figure 19. Construction of steel house.

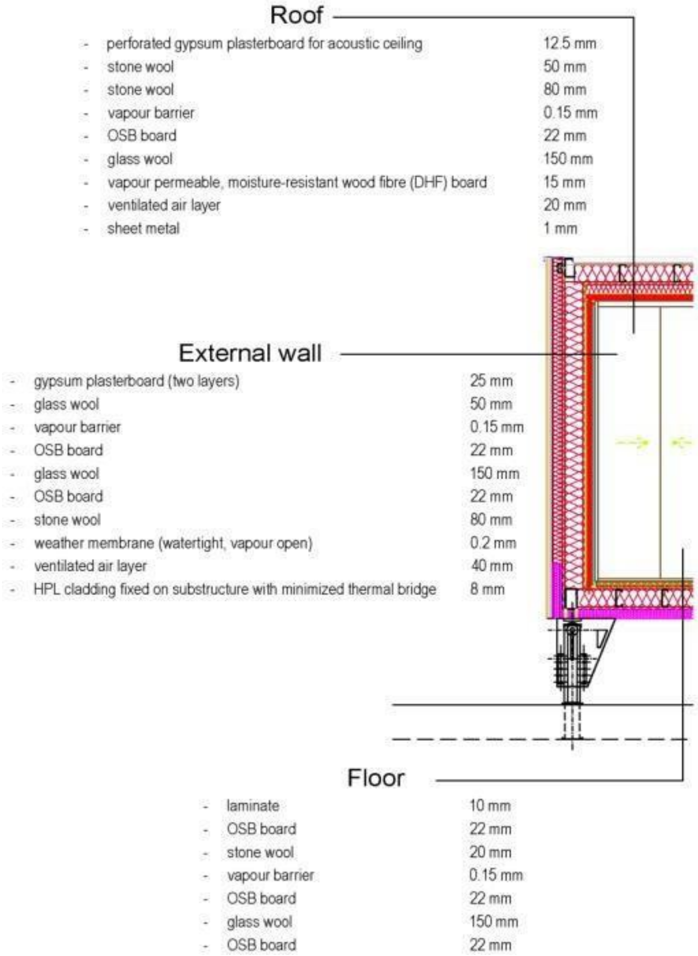

Figure 20. Wall construction.

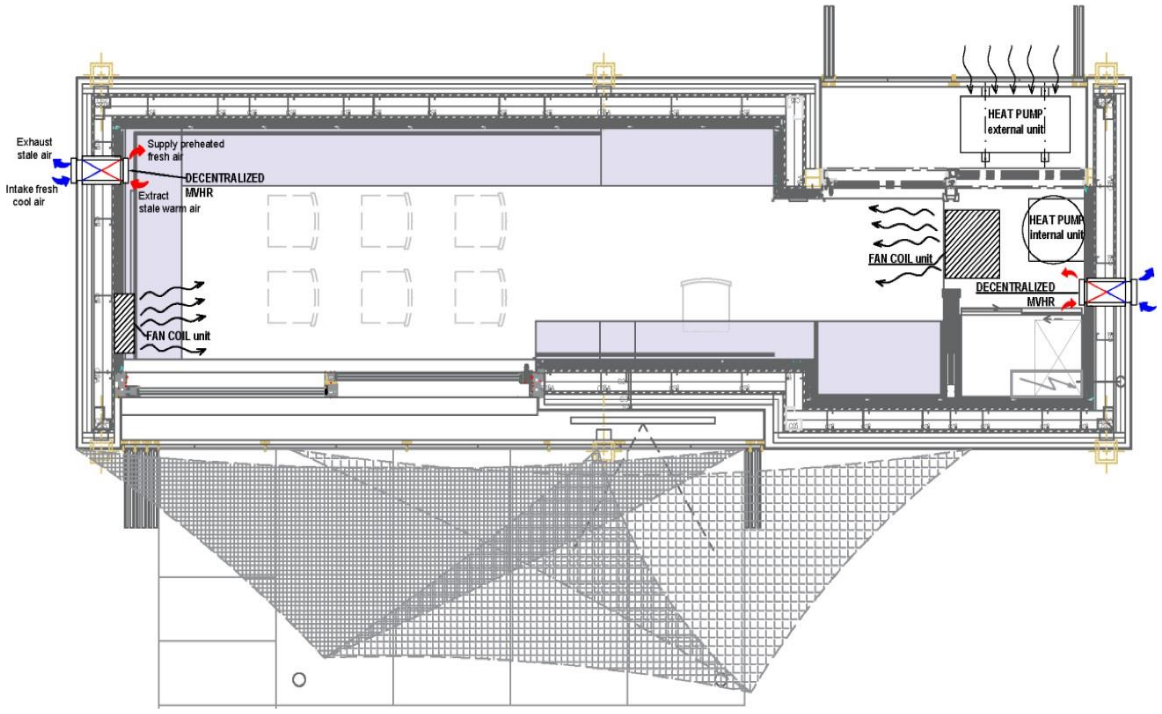

Figure 21. Plan.

CONCLUSION

This paper gives a thorough evaluation of the case study LSF building—the high-performance “MUZA” module, with a practical floor space of less than 50 m2—and suggests upgrading a traditional Lightweight Steel Frame (LSF) structure. A thorough analysis of the MUZA's performance was carried out, with particular attention paid to the impact of moisture condensation and thermal bridging on energy performance. To find out how the module functioned in various environments, more analyses that were reliant on orientation and climate were conducted. Based on the data that have been presented, it can be inferred that a more thorough and intricate analysis is needed to appropriately evaluate the thermal performances of LSF walls than is necessary for masonry or reinforced concrete buildings. This entails computing heat losses numerically, considering all steel studs and other.

REFERENCES

1. Broadbent C. Steel’s recyclability: demonstrating the benefits of recycling steel to achieve a circular economy. The International Journal of Life Cycle Assessment. 2016 Nov;21:1658-65.
2. Assadi MH, Doustkhah E. Transforming Cl-Containing Waste Plastics into Carbon Resource for Steelmaking: Theoretical Insight. ACS Engineering Au. 2023 Sep 15;3(5):285-91.
3. de Mattos Nascimento DL, Mury Nepomuceno R, Caiado RG, Maqueira JM, Moyano-Fuentes J, Garza-Reyes JA. A sustainable circular 3D printing model for recycling metal scrap in the automotive industry. Journal of Manufacturing Technology Management. 2022 Jul 4;33(5):876-92.
4. Indoria M, Kumar P, Panwar Y, Sharma T. Implementation of industry 4.0 to achieve sustainable manufacturing in steel industry: A case study. Systematic Literature Review and Meta-Analysis Journal. 2021;2(1):1-9.
5. Kanyilmaz A, Birhane M, Fishwick R, del Castillo C. Reuse of Steel in the Construction Industry: Challenges and Opportunities. International Journal of Steel Structures. 2023 Oct;23(5):1399-416.
6. Assefa, G., & Ambler, C. (2017). To demolish or not to demolish: Life cycle consideration of repurposing buildings. Sustainable Cities and Society, 28, 146–153.
7. Brockhaus S, Ginten M, Klein S, Teckert M, Stawicki O, Oevermann D, Meyer S, Storey D. In-line inspection (ILI) methods for detecting corrosion in underground pipelines. InUnderground pipeline corrosion 2014 Jan 1 (pp. 255-285). Woodhead Publishing.
8. Atherton J et al (2007) Declaration by the metals industry on recycling principles. Int J Life Cycle Assess 12(1):59–60
9. Haas, P.; Tran, F.; Blaha, P.; Schwarz, K.; Laskowski, R. Insight into the performance of GGA functionals for solid-state calculations. Phys. Rev. B 2009, 80, 195109,
10. Ramin, L.; Assadi, M. H. N.; Sahajwalla, V. High-density polyethylene degradation into low molecular weight gases at 1823 K: An atomistic simulation. J. Anal. Appl. Pyrolysis 2014, 110, 318– 321,

