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Towards Circular Construction: End-of-Life Scenario Analysis of Steel Structures Using Sustainable Life Cycle Approach

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ABSTRACT: The construction sector is responsible for 40% of the global natural resources exploitation, and 40% of CO_2 emissions. Steel is a key construction material with significant potential to support the transition to a low carbon-built environment due to its durability, recyclability, and ease of reuse. Recycling steel components is the most widely practiced method for managing steel at the End-of-Life (EOL) phase of structures. However, there is a significant gap in the literature regarding the impact of reusing steel components in comparison to recycling them, considering simultaneously the environmental and economic impacts. This study introduces scenario analysis for the EOL phase of steel structures considering their Global Warming Potential (GWP), Energy Demand (ED), and the associated costs. The study has the following steps: (1) Reviewing studies of the EOL phase, focusing on Life Cycle Assessment (LCA) approaches and deconstruction optimization; (2) Defining the possible EOL scenarios of steel structures and developing the mathematical formulation; and (3) Performing environmental and economic analysis for these scenarios. The case of the Original Champlain Bridge deconstruction in Montreal, Canada, was selected to assess the EOL scenarios. The results of the analysis indicate that when reuse is maximized to 80%, GWP and ED decrease by nearly 65% and 76%, respectively, compared to full-recycling scenario, while costs decrease by 20%. Achieving 90-100% reuse is the most sustainable option but requires optimized logistics, efficient storage, and rigorous steel quality control to be viable. While recycling is necessary for components that cannot be reused, it should be minimized whenever possible due to its high energy and cost implications.

1. INTRODUCTION

Over the last two decades, environmental concerns have driven the research of life cycle performance of constructed facilities towards a holistic approach to sustainability (Abouhelal et al., 2023). Consequently, circular construction concepts, such as circular economy principles for infrastructure, closed-loop construction, and Cradle-to-Cradle methodologies, have emerged as viable and effective alternatives for promoting sustainable development within the construction industry (Anderson et al., 2015). The current construction practices predominantly adhere to a linear supply chain model (take-make-dispose) that gives insufficient attention to the EOL phase of structure (Nik-Bakht et al., 2021). There is a need to change this model to a circular construction (CC) model that aims to keep resources in use as long as possible (Pomponi & Moncaster, 2017). Adopting CC is highly dependent on the way of handling the structure's components at the EOL phase. Deconstruction presents a primary enabler for the transition from a linear model to CC (Cristiano et al., 2021). It is a systematic process that relies on meticulously dismantling the structure in order to optimize the recovery of valuable components (Cheng et al., 2023). Following

deconstruction, there are two primary ways to handle recovered materials: recycling or reuse, which are frequently combined in actual projects (Ghisellini et al., 2018).

Steel is a key construction material with significant potential to advance CC and support the transition to a low-carbon built environment due to its durability, recyclability, and ease of reuse (Eberhardt et al., 2022). According to the World Steel Association, global steel production reached 1.9 billion tons in 2023 (Worldsteel Association, 2024). Recycling remains the predominant method for managing steel components at the EOL phase of structures. For example, in New Zealand, 85% of construction steel waste is recycled. However, steel manufacturing is fossil-fuel-intensive, emitting approximately two tons of CO_2 for every ton of steel produced (WSP, 2024).

While several studies have recognized the opportunity of the reuse of steel structure components at the EOL phase, most previous research has focused on the assessment of the environmental impacts of recycling versus virgin material use (Etienne et al., 2022; Mahpour, 2018; Sanchez & Haas, 2018).There is a significant gap in the literature regarding the impact of reusing steel components in comparison to recycling them, considering stimulatory the environmental and economic impacts. Accordingly, this study introduces scenario analysis for EOL phase of steel structures, considering Global warming potential (GWP), Energy Demand (ED), and the associated costs. The results provide quantitative insights to enhance decision-making at the EOL of steel structures.

2. LITERTURE REVIEW

Sanchez and Haas (2018) discussed the important role of green design methods and deconstruction planning methods in the adaptive reuse process of buildings. Green design methods are intended to reduce environmental costs and increase economic benefits over the entire product or service lifecycle. Examples of green design methods are design for assembly, supply chain management, product recovery management, Life Cycle Assessment (LCA), design for disassembly, design for remanufacture, and disassembly sequence planning (Smith et al., 2016).

LCA is an internationally recognized methodology (ISO 14040/2006; ISO 14044/2006) used to identifyand quantify the environmental impacts associated with products and processes (Ghisellini et al., 2018). In an LCA study, three different levels of system boundaries and processes can be adopted: (1) The *cradle-to-gate* approach includes the impacts of raw materials extraction, material production until the exit of the product from the factory; (2) The *cradle-to-grave* approach adds to these impacts the use stage and EOL stage, such as demolition and waste disposal in landfills; (3) The *cradle-to-cradle* approach further adds the impacts of extensive reuse and recycling of the waste (Ghisellini et al., 2018). The *cradle-to-cradle* approach incorporates reuse and recycling strategies to promote a zero-emission framework, maximizing resource utilization andminimizing waste (Thomas & Birat, 2013). Quantifying the environmental impacts of these approaches using LCA can promote the reuse of structure components at the EOL stage.

Etienne et al. (2022) evaluated the impact of reuse and reusability across different life cycle stages. They offered insights into the valuation of various reuse options for products when assessing their environmental impact utilizing LCA approach applied to a simplified case study focusing on carpet tiles. The study examined four use cases for product reuse: non-reusable virgin product, reusable virgin product, non-reusable reused products, and reusable reused product. For both the reusable virgin and reusable reused products, the reuse rate is set at 70%, with the remaining 30% following the default EOL scenario of incineration with heat recovery. In the evaluation, the study considered production, transport to construction site, installation, replacements, and EOLwith different options of reuse, recovery, and recycling. Results are presented for a reference study period of 10 years, corresponding to the expected service life of the floor finishing. The study's results reveal that the virgin reusable scenario has a smaller EOL impact since 70% of the tiles are reused.

Sanchez et al. (2020) conducted a multi-objective analysis for the selective disassembly planning for the adaptive reuse of an existing asset through the combination of different deconstruction methods. The environmental data for building components includes a LCA that evaluates selected environmental impacts,

specifically GWP and ED. Three different deconstruction methods were analyzed for the EOL phase per building component: 1) selective demolition, 2) destructive disassembly, and 3) perfect disassembly. Selective demolition is defined in this methodology as being synonymous with the destruction of components and connections. Destructive disassembly is defined as the disassembly of components and connections in a manner which preserves their physical integrity. Perfect disassembly is defined as the disassembly of building parts with extreme care in order to warrant their direct reuse (i.e., complete physical and functional utility). The economic data for building components includes the budgeting (bare cost) associated with each deconstruction method. The Sequential Disassembly Planning for Buildings (SDPB) method (Sanchez & Haas, 2018) is used to generate the optimized disassembly plans. At the end, a weighted multi-objective optimization analysis is implemented to generate a set of solutions that minimizes a specific environmental impact and the building cost.

Quéheille et al. (2024) proposed a many-objective optimization model that integrates cost, time, policy, and environmental impacts to identify optimal solutions for various case studies in the EOL phase of structures. Cost, delay, landfill rate, resource damage, ecosystem quality, and human health are the six objectives that are included in the model. The model is able to: (1) optimize both the demolition and waste management while considering the link between these two activities; (2) consider the different materials that make up the building and the possible waste treatments in order to be applicable to any case study; and (3) provide a complete assessment of the environmental impacts in order to avoid impacts transfer(i.e., improve one impact but degrade others). The solution utilized a meta-heuristic approach due to the problem complexity, which includes six objectives, 92 decision variables (both discrete and continuous) with non- linear relationships. The model could provide guidance for the decision-makers at the EOL phase.

Sobierajewicz et al. (2023) assessed the ecological and economic benefits of reusing steel hall structures through a Cradle to Cradle (C2C) model, as opposed to the traditional linear cradle to grave (C2G) approach. The study employed LCA to evaluate the cumulative ecological, economic, and technical impacts of reusing structural elements across multiple life cycles. It proposed a methodology for calculating ecological amortization and a generalized ecological indicator for quickly assessing the ecological impacts of multi-use steel halls. The findings highlighted that reusing steel components not only reduces negative environmental impacts but also improves economic outcomes, supporting the transition to a CC.

Basta et al. (2020) developed a BIM-based framework to assess the deconstructability of steel structures, specifically evaluating the potential for reusing steel components. The framework incorporates key parameters such as disassembly complexity, material recoverability, and repurposing potential utilizing BIM. The results highlighted the feasibility of efficient steel component reuse, contributing to waste reduction and the promotion of sustainable construction practices.

Ness et al. (2015) investigated new approaches to the reuse of steel in construction, focusing on the integration of digital tracking and modeling technologies. The study explored how digital tools could enhance the reuse process by improving the traceability and repurposing of steel components from deconstructed buildings. It examined key parameters such as the use of tracking systems and modeling technologies to facilitate the identification, assessment, and repurposing of steel materials. The findings indicated that these digital tools significantly increase the efficiency and effectiveness of steel reuse, providing a streamlined approach for evaluating the viability of reusing steel in future projects.

Existing research on deconstruction of steel structures has made valuable contributions but remains limited in scope. As mentioned before, recycling steel components is the most widely practiced method for managing steel at the EOL phase of structures. Current literature primarily focuses on studying the environmental impacts associated with recycling steel components vs. the use of virgin materials. They often neglect the potential benefits associated with reusing building components after deconstruction in favor of recycling and disposal possibilities. Furthermore, their analysis relies solely on environmental assessments, overlooking the inclusion of economic factors associated with the deconstruction process and supply chain activities. It is essential to integrate these economic considerations to provide a more comprehensive evaluation of the overall impact. However, there is a significant gap in the literature regarding the impact of reusing steel components in comparison to recycling them, considering stimulatory evaluation of the environmental and economic assessment.

3. PROPOSED METHOD

3.1 EOL scenarios of steel structures

The deconstruction process at the EOL phase of a structure follows a systematic approach to maximize component reuse and recycling, reducing environmental impact and promoting CC. Figure 1 illustrates the stages involved in the EOL phase of structures. The process begins with the identification of a donor structure, where a structure suitable for deconstruction is selected. A pre-deconstruction audit is then conducted, including a comprehensive evaluation of the donor structure to identify reusable, recyclable, or disposable components. The audit assesses the economic and environmental feasibility of deconstruction, providing essential data that guides the development of the deconstruction planning and permitting stage (Riuttala et al., 2024). During this stage, a comprehensive deconstruction plan is created, which includes securing the necessary permits, coordinating logistics, and organizing the workforce and equipment. This process ensures that the deconstruction is carried out efficiently, safely, and in full compliance with regulatory standards and safety protocols. Once planning is complete, the deconstruction stage follows, where the structure is methodically dismantled to recover intact components, minimizing damage (Harala et al., 2023). Subsequently, in the transportation off-site stage, recovered materials and components are transferred to processing or storage facilities for further assessment. Following this, the component testing & assessment phase evaluates the materials for structural integrity, safety, and compliance with standards to determine their suitability for reuse or recycling. Reusable components proceed to the reuse pathway, where they are refurbished, certified, and stored for future use in projects, thereby enhancing resource efficiency. For structural components intended for reuse, a certification process is conducted to ensure compliance with safety and performance standards. These components are then reused in new structures, reducing the demand for virgin raw materials. Similarly, components deemed suitable for recycling are processed in the recycling pathway, where they are transformed into raw materials for new steel components. This structured deconstruction process enables efficient resource recovery, minimizes waste, and supports sustainable construction practices by reducing carbon footprints and conserving natural resources. It is important to note that the actual decision to reuse or recycle structural steel at the EOL phase depends not only on environmental and economic considerations but also on technical assessments of the components. These assessments typically include visual inspections, mechanical testing (e.g., tensile strength, toughness), and certification processes to ensure compliance with current structural standards. For certifying structural steel or quality control procedures in the steel industry, both ISO (ISO, 2025) and ASTM (ASTM, 2025) standards provide essential frameworks. These standards involve evaluations such as material non-destructive testing and inspections of structural integrity to ensure the steel's reliability and safety in new applications. In this research, eight different scenarios are analyzed for the EOL phase using different proportions of reused and recycled steel to evaluate the environmental and economic impacts of each scenario.
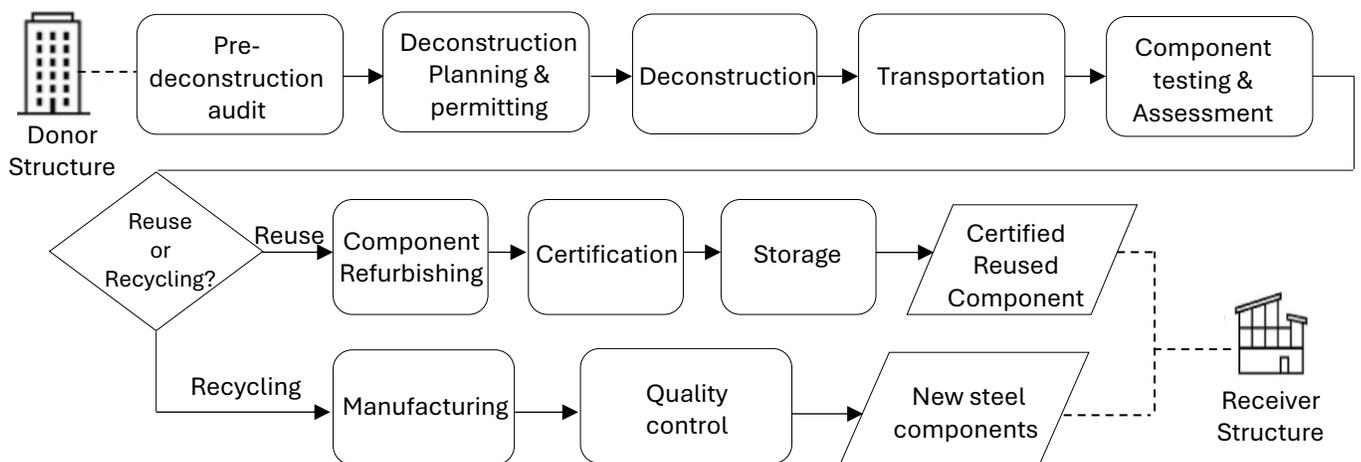

Figure 1: Deconstruction processes

3.2 Environmental and Economic Assessment for the EOL scenarios

Partial LCA is conducted to evaluate the GWP and ED of each scenario. This partial LCA includes the deconstruction process, the processing of steel components for reuse or recycling, and transportation to the reuse storage or recycling facility. The study incorporates the associated costs for each EOL scenario to provide valuable insights for both environmental and economic impacts. Table 1 shows the factors considered in calculating GWP, ED, and cost. The equations for GWP and ED are adapted from the generic equations presented by (Kim & Kim, 2021), while the cost equation is adapted from (Sanchez et al. 2020). For calculating GWP for the deconstruction works (GWP_d), Equation 1 is formulated, where the total CO_2 emissions generated from deconstruction due to the use of diesel fuel by cranes. The number of utilized cranes, and the lifting rate per crane (LR_{crane}) are identified based on the complexity and the scale of the structure. Since reuse requires more careful dismantling compared to recycling, the lifting rate and the number of cranes must reflect these different operational constraints.

Table 1: Assumptions of CO_2 emissions, energy demand and cost

Process	Factor	Description	Value	Unit
Deconstruction	η_c	Crane fuel efficiency[1]	5.1	L/h
	ε_{CO2}	CO_2 emissions of diesel fuel[1]	2.677	Kg CO_2/L
	γ_f	Energy content of diesel fuel[2]	35.8	MJ/L
Reuse	$\varepsilon_P^{Reu.}$	Reuse CO_2 emission[3]	0.05	ton CO_2
	$\gamma_P^{Reu.}$	Reuse embodied energy[3]	100	MJ/ton
	$E^{Reu.}$	Reuse energy consumption[3]	100	Kwh / ton
	$C_e^{Reu.}$	Energy cost per KWh[4]	0.08	\$/KWh
	$D^{Reu.}$	Reuse deconstruction cost[1]	384	\$ /ton
	$C_l^{Reu.}$	Processing labor cost[5]	50	\$ /h
	$C_{QC}^{Reu.}$	Processing QC costs[5]	20	\$ /ton
Recycling	$\varepsilon_P^{Res.}$	Recycling CO_2 emission[1]	0.3	ton CO_2
	$\gamma_P^{Res.}$	Recycling embodied energy[2]	3000	MJ/ton
	$E^{Res.}$	Recycling energy consumption[2]	400	Kwh / ton
	$D^{Res.}$	Recycling deconstruction cost[5]	134	\$ /ton
	$C_l^{Res.}$	Processing labor cost[6]	60	\$ /h
	$C_{QC}^{Res.}$	Processing QC costs[6]	30	\$ /ton
Transportation	η_f	25-ton truck fuel efficiency[1]	23	L/h
	C_h	Truck hourly transportation cost[1]	84.89	\$/h

[1](Kim & Kim, 2021); [2](IPCC, 2019); [3](Worldsteel Association, 2024); [4](CSPA, 2025); [5](Sanchez et al. 2020); [6](Canadian Industry Statistics, 2025).

[1] $GWP_d = (W^{Reu.\&Res.)}/ LR_{crane}^{Reu.\&Res.}) \times \eta_c \times \varepsilon_{CO2}$

Equation 2 is used for evaluating GWP for steel processing, where (Reu.) refers to steel reuse, and (Res.) is recycling, while ($W^{Reu.\&Res.)}$ is the weight of steel being processed for reuse or recycling.

[2] $GWP_P^{Reu.\&Res.} = W^{Reu.\&Res.} \times \varepsilon_P^{Reu.\&Res.}$

For assessing the transportation emissions, Equation 3 is used, where ($D^{Reu.\&Res.}$) is the distance to reuse storage or recycling facility, (S) is the truck speed, and (C) refers to the truck capacity.

[3] $GWP_t^{Reu.\&Res.} = (W^{Reu.\&Res.)}/C) \times (D^{Reu.\&Res.)}/S) \times \eta_f \times \varepsilon_{CO2}$

Moving to the ED, Equations 4, 5, 6 are formulated to calculate the ED for deconstruction works, steel processing, and the transportation energy, respectively.

$$[4] \ ED_d = (W^{Reu.\&Res.)} / LR_{crane}^{Reu.\&Res.}) \times \eta_c \times \gamma_f$$

$$[5] \ ED_P^{Reu.\&Res.} = W^{Reu.\&Res.} \times \gamma_P^{Reu.\&Res.}$$

$$[6] \ ED_t^{Reu.\&Res.} = (W^{Reu.\&Res.)}/C) \times (D^{Reu.\&Res.)}/S) \times \eta_f \times \gamma_f$$

The cost for the deconstruction process is estimated according to the scale of the deconstruction project, whereas Equation 7 is used for calculating steel processing cost, and Equation 8 is formulated to calculate the transportation cost.

$$[7] \ C_P^{Reu.\&Res.} = C_e^{Reu.\&Res.} + C_l^{Reu.\&Res.} + C_{QC}^{Reu.\&Res.}$$

$$[8] \ C_t^{Reu.\&Res.} = (W^{Reu.\&Res.)}/C) \times (D^{Reu.\&Res.)}/S) \times C_h$$

4. CASE STUDY

To demonstrate the practical application of the proposed methodology, the case of the Original Champlain Bridge deconstruction in Montreal, Canada, is examined. This bridge, built in 1962, was one of the largest infrastructure projects in North America. The bridge faced several significant structural problems that contributed to its eventual deconstruction (JCCBI, 2025). Mechanical connections enable easier component separation during deconstruction, using techniques like heat cutting for large elements, unbolting, and removing Rivet. The bridge's deconstruction produced approximately 25,000 tons of steel, with structurally viable components for salvage and repurposing. The proximity of the bridge with transportation infrastructures facilitated the deconstruction process and enhanced the reuse of components by providing easy access for logistics, as well as enabling efficient removal and transport of salvaged materials.

For conducting the assessment, the study assumed that the crane lifting rate is 5 tons/h for reuse due to the extra precautions required, such as slow cutting and controlled disassembly. In contrast, recycling allows for faster, more straightforward lifting, with an estimated rate of 10 tons/h per crane. Also, the study assumed that components are transported between locations at a speed of 40 km/h using a 25-ton truck. The transportation distance to recycling facility is 150 Km, while the transportation to reused components storage is 50 km. The estimated energy consumption cost for reuse includes cleaning, inspection, and repairs, while the recycling energy costs includes melting scrap steel in an Electric Arc Furnace (EAF). For calculating the labor cost for reuse processing, the study assumed that it takes about 4 hours of labor per ton of steel, while for the recycling the process takes 10 hours to produce 1 ton of steel. The QC costs of reuse include the minimal refurbishment costs, and for recycling includes the costs related to emissions control and regulatory compliance.

Figure 2(a) illustrates the GWP for different EOL scenarios, representing percentage of steel reuse, while the remaining portion undergoes recycling. The results indicate the highest GWP is achieved in the case of full recycling due to high emissions from the recycling process, which is energy intensive. Conversely, at 80% reuse, GWP decreases by approximately 65% compared to the full-recycling scenario. This significant reduction is attributed to the reduction of emissions associated with recycling processing. ED follows a similar trend to GWP (Figure 2(b)), where increasing the reuse percentage results in a substantial reduction in total ED. The highest ED occurs in the full recycling case, primarily due to the energy-intensive processes required for melting and reshaping steel. In contrast, at 80% reuse, ED is reduced by approximately 76% compared to full-recycling scenarios. Figure 2(c) illustrates the cost for each EOL scenario. The cost assessment of different scenarios shows that increasing reuse leads to significant financial savings compared to recycling. In the full recycling scenario, total costs are the highest, driven primarily by recycling expenses, which include energy consumption, labor, and processing. As reuse increases, costs decline steadily, with an estimated 20% reduction in total costs at 80% reuse. Transportation to storage costs

slightly increase at higher reuse levels. However, the cost savings from reduced recycling far outweigh the additional transportation cost. Therefore, reuse not onlyminimizes environmental impact but also provides considerable economic benefits, making it the preferred option for steel EOL management. The overall analysis reveals that the higher reuse levels significantly reduce the GWP, ED, and costs, making them the most sustainable and cost-effective options. In contrast, recycling leads to the worst environmental and economic outcomes due to its high energy consumption and processing costs, so it should be minimized whenever possible. Also, scenarios below 50% reuse offer limited sustainability and cost benefits, making them less effective. The most significant improvements occur between 60% and 100% reuse, where both savings and sustainability benefits increase rapidly. While 100% reuse provides the highest cost savings (25%), it requires careful optimization of transportation to remain efficient. For a practical and balanced approach, targeting a reuse level of at least 70-80% provides an optimal balancebetween environmental impact reduction and economic efficiency.
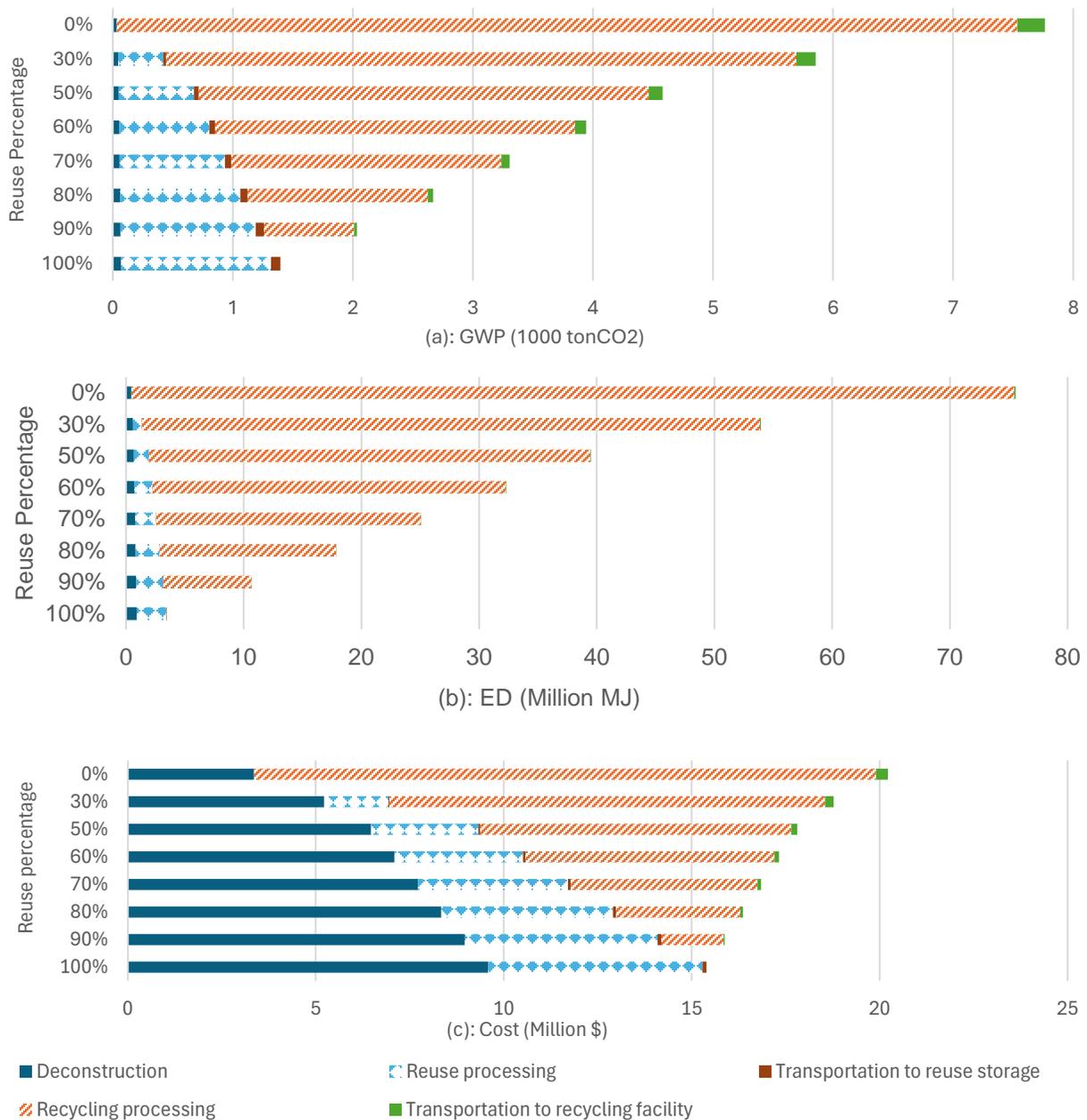

Figure 2: GWP, ED, Cost for EOL scenarios

5. BARRIERS AND RECENT INITIATIVES FOR STEEL REUSE

To contextualize the findings of the case study and highlight key challenges to practical implementation, this section presents an overview of the main barriers to structural steel reuse. The identified barriers can be categorized in the following categories:

(1) Deconstruction issues: There is a shortage of skilled workers trained in deconstruction, compared to traditional demolition methods. Deconstruction requires using remote-controlled, high-reach equipment, which may have significant positive impacts for the health and safety of workers (*JCCBI*, 2025).

(2) Reverse supply chain issues: The challenge lies in ensuring the availability of reclaimed components in the desired size, volume, and location (Ghorab & Hammad, 2025). There is a Lack of communication and sharing information through the supply chain and risk sharing between companies (*JCCBI*, 2025). Also, according to direct communication with CANAM Company, Canada, a significant barrier to steel reuse is the lack of a centralized platform for developers, engineers, and fabricators to easily access available reclaimed steel. A public "Steel Reuse Marketplace" would provide a catalog of available steel sections, enabling users to view current stock and identify potential 'donor' buildings set for demolition. Another barrier in this area is the need for a protected storage space for cataloging and managing reclaimed steel members. One promising solution is the development of component or product passports that include data, such as material specifications, load history, maintenance records, and fatigue cycles (McIver, 2024). There is a need for a detailed knowledge of the steel component's properties and in-use history through creating product passports (Çetin et al.,2023).

(3) Quality issues: The perception that reclaimed steel is inferior to new steel, combined with client expectations for reused components to be cheaper and a lack of commercial incentives, creates a barrier to steel reuse. Investment in inspections, documentation, and tracking, as well as the standardization of responsibilities and inspection methods, are essential to facilitate the trade of reused steel. The Steel Construction Institute(SCI), UK, has published key technical standards for steel reuse. *P427 Structural Steel Reuse* is used for the assessment, testing and design Principles. *P440 Reuse of Pre-1970 Steelwork* is a supplement to P427. These standards provide a comprehensive technical basis for the engineering and construction community for incorporating reused steel safely in new construction (ReNewCANADA, 2024).

(4) Cost issues: To catalyze the adoption of steel reuse, there is a need to establish a government incentive program. The creation of a carbon credit system, providing financial incentives to the salvage steel stockists, contractors, and developers, would facilitate investment in systems and infrastructure needed to make steel reuse standard practice. These incentives will encourage more stakeholders to engage in steel reuse, fostering a circular supply chain between deconstruction and new construction industries (ReNewCANADA, 2024).

(5) Issues related to design tools: There is a need to develop design tools that can consider reusable components. For example, WSP company, Canada, developed a digital steel reuse tool to offer an effective way to reduce embedded carbon in building design, promotes the CC, and reduces carbon emissions. The tool takes the steel structural elements of the design and finds matches for them, working out how the reclaimed sections can be integrated seamlessly with new sections without any loss of quality. The tool ensures that, on average, 90% of the available length of reclaimed steel sections is used. The tool has enabled projects like the Elephant & Castle Town Centre to replace 74 tons of new steel with reclaimed steel, saving 125 tons of CO_2. In another case, a London headquarters refurbishment using 100% reclaimed steel, in collaboration with WSP and Cleveland Steel, save 35 tons of CO_2 (McIver, 2024).

(6) Regulation issues: Several initiatives are being actively implemented to enhance the reuse of steel components, focusing on reducing waste and advancing sustainability within the construction sector. For example, the city of Toronto, Canada, introduced a set of environmental performance standards called the Toronto Green Standard (TGS). The goal is to accelerate GHG emission reduction targets for structures built from 2025, with a focus on achieving near-zero emissions by 2030. Embodied carbon assessments (e.g. LCA) are a crucial component of the TGS, particularly in higher tiers where these evaluations become mandatory. These assessments enable developers to quantify and report the carbon emissions associated with building materials and construction processes, emphasizing the importance of low-carbon materials in achieving TGS targets. The City of Toronto enforces TGS requirements through the Site Planning Approval (SPA) process, ensuring that TGS requirements are incorporated into project designs (Carroll, 2024).

6. CONCLUSIONS AND FUTURE WORK

The transition to CC is increasingly vital as the construction industry confronts pressing challenges related to climate change, carbon emissions, and resource depletion. The EOL phase of structures is crucial for minimizing environmental impacts and conserving resources by promoting efficient component reuse and material recycling. This study emphasizes the need for a shift towards CC, particularly through the reuse of steel components. It introduces scenario analysis for the EOL phase of steel structures considering their GWP, ED, and the associated costs. The results show that GWP and ED decrease by nearly 65% and 76%, respectively, while costs decrease by 20% when reuse is maximized to 80%. Achieving 90-100% reuse is the most effective strategy for reducing GWP, ED, and costs. However, challenges such as infrastructure for reuse and steel quality control must be addressed. Recycling, while necessary for components that cannot be reused, should be minimized whenever possible due to its high energy and cost implications. By implementing high reuse targets, optimizing transportation, and improving deconstruction efficiency, industries can achieve sustainable and cost-effective steel lifecycle management.

This study conducted partial LCA, focusing on the deconstruction process, structural steel processing, and transportation to the respective facility. Future research should extend the LCA to a cradle-to-cradle analysis, covering the entire second life of structural steel components. This would involve a more detailed consideration for the reverse supply chain factors, such as disassembly techniques, logistics, storage conditions, and the potential for further processing or upgrading of components. Also, future work should integrate material testing and quality assessments to improve the accuracy and reliability of steel reuse evaluations within the deconstruction framework. Moreover, the comparative analysis in this study is based on simplified scenarios considering the amounts of reused vs. recycle steel based on weight. Future work should adopt a simulation-based optimization approach to improve sustainability and resource efficiency by accounting for the unique characteristics of each component, the deconstruction processes, and reverse supply chain factors. Also, future work would benefit from incorporating additional digital technologies, such as integrating BIM with material passports and Environmental Product Declarations (EPDs) to enhance the deconstruction process and provide more comprehensive data on the reused steel components. Finally, the current study is based on deterministic LCA and cost analysis. Future research should incorporate sensitivity analysis and Monte Carlo simulation to improve the reliability of the results by accounting for uncertainties in deconstruction and reverse supply chain processes.

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