Enablers, opportunities, and challenges of steel reuse in the AEC industry

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ABSTRACT

The Architecture, Engineering, and Construction industry is experiencing a paradigm shift towards a Circular Economy (CE) model, promoting material reuse to minimize waste and maximize resource value. This research delves into stakeholder perceptions of steel reuse, focusing on its acceptance, resistance, and associated decision-making process to support the implementation of CE practices in our industry. Semi-structured interviews were conducted, revealing a complex landscape. Through in-depth qualitative analysis, the research identifies various opportunities, challenges, and uncertainties associated with the use of reused steel. Key findings reveal a complex interplay of reused steel as both a cost-saving driver and a challenge, diverging perspectives on certification and a significant shift in design practices. Recommendations include fostering industry-wide standards and collaborative initiatives for a more sustainable Architecture, Engineering, and Construction industry. Future work entails expanding the study's scope for broader insights, while the present findings contribute valuable perceptions for fostering steel reuse adoption.

RESEARCH PROBLEM STATEMENT

The deteriorating state of Earth's ecosystems demands immediate attention. The Architecture, Engineering, and Construction (AEC) industry consuming 50% of all natural material resources (Khodeir and Othman 2018), plays a pivotal role in shaping our planet's future. While some of the resulting waste is recycled, a staggering 75% of construction waste is estimated to be disposed of in landfills, generating 600 million tons of debris in 2018 (United States Environmental Protection Agency 2018). Simultaneously, the global demand for steel has increased twofold since 2000 (International Energy Agency 2020), a trend projected to persist in the absence of substantial systemic changes, mirroring the continuous growth of the global population (United Nations 2022).

Previous research has highlighted the limitations of our industry's current linear "take-make-dispose" approach, which involves using materials to construct buildings and then disposing of them at the end of their useful life. This single-use model disregards the potential for material reuse after the end-of-life (EOL) phase. However, a paradigm shift towards a Circular Economy model has emerged within the industry over the past few decades. This approach aims to keep materials in a closed loop, maximizing their value and minimizing waste generation and resource extraction (Ellen MacArthur Foundation 2013). Despite the growing recognition of circularity and material reuse as essential principles within the AEC industry, research on stakeholder perceptions of material reuse in building design and construction remains limited (Shooshtarian et al. 2020). While some studies have identified potential barriers and enablers of reuse (Lu et al. 2020; Oyedele et al. 2014; Shooshtarian et al. 2020) further research is needed to characterize perceived challenges and opportunities, identify uncertainty and information needs, and address these shortcomings to facilitate future adoption. Previous research has highlighted the tendency of architects and structural/civil engineers to specify conventional materials over recycled products due to unfamiliarity, adherence to standards, and concerns about liability for building performance

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(Knoeri et al. 2011). Similarly, studies of contractors/builders have revealed a lack of experience and knowledge of recycled products, leading to a reluctance to use materials perceived as unconventional (Tam et al. 2009). Concerns regarding the perceived lack of information on material availability, market accessibility, application guidelines, and government support have also been raised, emphasizing the need for increased information dissemination and training initiatives (Shooshtarian et al. 2020). To address these gaps, a preliminary analysis of stakeholder perceptions, the factors influencing acceptance or resistance to material reuse, and information needs is crucial to determine opportunities for expanded use and adoption in the AEC industry.

RESEARCH METHODOLOGY AND APPROACH

To answer these questions, we conducted exploratory, semi-structured interviews with eight industry professionals responsible for different decisions related to steel reuse in the AEC industry. The University of Colorado Boulder's Institutional Review Board reviewed and approved this research protocol (#23-0488). Interviewees included owners, contractors, architects, subcontractors, civil engineers, and structural engineers within the United States and had experience ranging from 10 to 30 years in the industry. Table 1 offers an overview of participant information, including professional roles, and years of experience. The professional role of construction includes contractors and subcontractors while engineering professional roles include architects, civil engineers, and structural engineers. Tailored interview questions focused on each stakeholder's role, specifically targeting their perceptions, behaviors, and decision-making processes concerning steel reuse within the design and construction process.

Table 1: Participants information

Participant	**Professional role**	**Years of experience**
P1	Construction	20-30 years
P2	Construction	20-30 years
P3	Jurisdiction	10-15 years
P4	Deconstruction	15-20 years
P5	Construction	20-30 years
P6	Owner	20-30 years
P7	Engineering	10-15 years
P8	Engineering	10-15 years

We transcribed the interviews using Trint software ("Transcribe video and audio to text | Content editor | Trint" 2022) and reviewed the transcriptions for accuracy. Subsequently, the interview data was imported into the qualitative coding software NVivo (NVivo 2023), where we coded the interviews deductively into three parent codes: Opportunities, challenges and barriers, and uncertainties, as shown in Table 2 (Saldaña 2021).

Table 2: Parent codes and examples

Parent codes	**Description**	***Example Interview Segment***
Opportunities	Positive aspects and advantages associated with the reuse of steel.	*"So, if you have a building where [...] you already [....] know this beam, this beam, and this beam,* [...are going to be] *reused, well, I don't have to wait 4 to 6 weeks. I can just go pick it up. So that would help with procurement times for sure."*
Challenges/Barriers	Obstacles and difficulties that stakeholders encounter or	*"I think it's really complicated to reuse that sort of material...because it's going to be rare to have the right shape and size for what you need"*

Parent codes	Description	*Example Interview Segment*
	foresee in the process of reusing steel.	
Uncertainties	These are areas where stakeholders express doubts, lack confidence, or face ambiguity regarding the reuse of steel.	*"But from kind of a contractual aspect of it, the stockpile itself and the deconstruction side of it really is not guaranteeing the quality of the steel."*

These coded interview segments were then inductively coded into child nodes within each category to identify common advantages, barriers, and uncertainties related to steel reuse. The child codes encapsulated the nuanced aspects of each parent code, providing a detailed understanding of the underlying dynamics. For instance, consider the following passage:

"I think the biggest thing that we face as an industry with recycling ... any material—is solely the cost right now. Recycling should be where you get paid to recycle, right? More often than not, you're actually paying money to recycle materials, and that's typically the owner's biggest gripe with recycling materials: one, it costs money and time, and time is money. So, I think that's probably the biggest thing that I've seen."

We deductively coded this passage into the parent code "Challenges," since the cost is presented as a barrier to recycling, and then inductively coded this into "Cost" and "Time constraints." Subsequently, we affinity-grouped these codes into factors that had similar themes related to acceptance or resistance to steel reuse in the AEC industry. Moreover, to delve deeper into data relationships, the researchers conducted crosstab queries on the frequency of the child codes and their correlation with stakeholders. Furthermore, it is important to discern when these factors exert more influence during the design and construction process. Therefore, the authors examined and correlated the factors that influence decision-making on the use of reused steel within the project phases reference by stakeholders, offering insights into the timing for addressing these considerations.

KEY FINDINGS AND IMPLICATIONS

The preliminary semi-structured interviews aimed to identify factors influencing the acceptance or resistance to steel reuse and ascertain opportunities for its expanded use and adoption within the building sector. This section will cover the primary results from the qualitative analysis of the data for opportunities, challenges/barriers, and uncertainties. Table 3 provides detailed information on parent codes, factors, child codes, and the occurrence of factors.

Table 3: Parent codes, factors, and child codes

Parent codes	Factors	Frequency	Child codes
Opportunities	Infrastructure and planning	7	*Material stock bank* *Storage availability* *Targeted reuse strategy* *Testing technology*
	Cost	6	*Cost savings*
	Engagement and collaboration	5	*Community engagement* *Environmental consciousness owners* *Project collaboration*
	Time	5	*Time savings*

Parent codes	Factors	Frequency	Child codes
	Regulatory support	3	*Regulatory support* *Supporting sustainability*
Challenges/ Barriers	Cost	7	*Cost* *Low tipping fees*
	Market and industry influences	7	*Feasibility of salvage* *Industry novelty* *Inadequate storage facilities* *Space availability* *Specific training* *Suitable off-taker*
	Operational constraints	7	*Testing* *Time constraints* *Transportation* *Urban level*
	Project planning and execution	7	*Aesthetic challenges* *As-built documentation* *Coordination* *Design constraints* *Design needs* *Front-End preparation* *Overbuild construction* *Permitting*
	Regulatory support	4	*Lack of regulations* *Lack of subsidies for reuse*
	Misconceptions	3	*Lack of consideration for used materials* *Misconceptions surrounding the environmental impact of reusing* *Emphasis on recycling over reuse*
Uncertainties	Cost	4	*Unknown cost impact*
	Design and specifications	4	*Building variations* *Compatibility and design specifications*
	Future planning	4	*Condition and suitability for reuse* *Unknown future use*
	Process and operational	4	*Data gathering* *Process efficiency* *Re-certification* *Storage logistics* *Unknown effort for reuse*
	Material and procurement	2	*Material availability* *Procurement timing impact*
	Jurisdictional	1	*Jurisdictions variations*

Reviewing these factors across categories, we identified three themes influencing steel reuse in the industry. First, our analysis unveils a nuanced perspective on the role of cost in decision-making during the EOL phase. Second, engineers emphasized that reusing steel has the potential to impact the design phases significantly. Lastly, our key findings highlight varying perspectives among stakeholders, particularly contractors, and jurisdictions, regarding the use of recertified and tested reused steel.

Cost dynamics at the EOL phase

Through our analysis, we discerned that the role of costs extends beyond being a mere static factor; instead, it operates as a dynamic factor, capable of acting as both a driver and a challenge in the decision-making process at the EOL phase. As represented in Table 3, interviews highlighted cost as a potential opportunity, challenge, and uncertainty. This interplay reveals that cost considerations can propel decisions forward or present challenges. Contractors emphasize that owners perceive the utilization of reused steel as a strategic cost-saving approach. This illustrates that owners view reused steel as a measure to save costs, positioning it as a driver in the decision-making. A participant highlighted this owner-driven motivation:

"That was an owner request on the project, trying to save money as can we reuse because the structure, we were putting up was basically just replacing an old one that the exterior sheet metal and everything was just rusted and rotted."

This underscores an owner's motivation, emphasizing the financial advantages associated with reused steel. However, engineers expressed reservations about the unknown costs related to the deconstruction process. Despite potential material cost savings, uncertainties related to the effort and expenses required for extraction present a significant challenge. An engineer stated that owners worry about the economic factors related to deconstruction:

"But a couple of projects had their own major budget issues, so they were needing to go through value engineering regardless of the structural steel […] We can't add in this innovative element, whether or not […] they wanted to. But it was just it was almost just too much from an effort perspective. Unknown cost is really what it was."

Researchers further explore the dynamics between cost and the project phases. Figure 1 represents the relationship between cost and project phases.

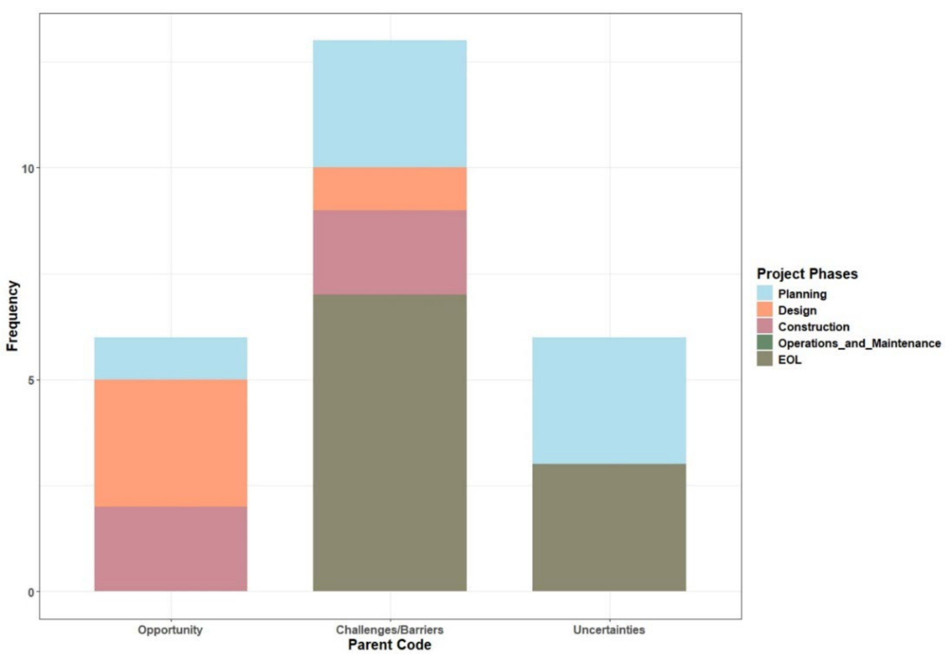

Figure 1: Bar Chart Relationship between cost and project phases

The uncertainties, all of which have cost implications, reveal a significant relation with both the planning phase and the EOL phase. This correlation is tied to the inherent uncertainty in deconstruction costs and the unpredictability surrounding the resale value of materials. The intricate relationship becomes more apparent when considering the transition from the disposal phase to the conceptual planning phase of a new building. When a project evolves from the deconstruction process, the subsequent EOL phase effectively transforms into the planning phase for constructing a new building.

This supports a closed-loop system, highlighting a circular approach where the conclusion of one project seamlessly aligns with the initiation of another. The observed relation underscores the potential for a sustainable and interconnected construction process. It demonstrates how uncertainties in cost can significantly influence the broader lifecycle of construction projects, facilitating more informed decision-making and resource management in our industry.

A crucial factor to consider between EOL and project initiation is the impact of low tipping fees, which was identified as a challenge during the EOL phase. As eluded to within the coding example, one participant shared that the cost-benefit ratio is currently not in place to support steel reuse as tipping fees, or the cost to 'dump' or dispose of steel at a landfill, are so low:

"I guess ... this comes up again for all materials is how low our local tipping fees are. So, you know, material re-use, in places where you don't have an easy way to get rid of this stuff, reuse becomes a more attractive option, and right now, our tipping fees are some of the lowest in the country, and I think that relates to why material reuse and recycling are also fairly low."

This underscores the potential for adoption challenges to persist. If the cost to discard (tipping fees) and purchase new steel remains considerably lower than the cost of reuse, it introduces a considerable constraint. The economic feasibility of steel reuse initiatives is heavily influenced by the comparative costs associated with discarding and acquiring new steel.

In summary, cost considerations during the deconstruction process emerge as both a potential driver and a challenge for owners. This prevalent emphasis on economic considerations underscores the significant role financial factors play in driving the momentum toward the adoption of steel reuse initiatives. While owners express interest in deconstruction due to potential cost savings associated with reusing steel, they also perceive costs as a concern, including the time required to extract and verify quality materials, which also relates to uncertainty. This duality of cost, acting both as a driving force and a challenge, offers a comprehensive understanding of the intricacies in the decision-making process at the end of a building's life. It signifies that decisions are not solely dictated by potential savings but are contingent on specific circumstances and priorities of stakeholders, contributing to a more nuanced discourse on sustainable construction practices.

Trust-dynamics on recertified and tested used steel

A notable contrast emerges between contractors and jurisdiction on one hand and engineers on the other. Contractors and jurisdictions do not face constraints in using reused steel if it has been previously recertified and tested. However, engineers express concerns about the data provided by other engineers regarding certification and testing. Contractors emphasize the significance of certification and testing documents in determining the suitability of reused steel. The following statement underscores the reliance of contractors on certification as a critical factor influencing their decision-making process: *"As long as it's got certification that is tested […] my owner and engineer have no issue with it."* This reliance suggests that contractors perceive certification as a robust indicator of quality and safety of reused steel, providing them with the assurance needed for its utilization. Similarly, jurisdictions rely on the expertise of structural engineers in the review, and approval of structures containing reused materials. The subsequent statement emphasizes the jurisdiction's reliance on structural engineering validation for approving structures with reused elements:

"Everything in our whole jurisdiction is engineered, and that means a structural engineer has to look at it […] So as long as the structural engineer says it's okay […] But as a jurisdiction, we don't care. We're going to get a stamped structural drawing,"

However, while contractors and jurisdictions express confidence in reused steel upon certification, engineers voiced reservations about relying on information provided by other engineers during the deconstruction phase. The data points to engineers conducting their own measurements, and double-checking, indicating a level of skepticism, and a desire for personal validation. The following statement suggests that engineers perceive their own expertise as crucial in assessing and validating the suitability of reused steel:

"Our structural engineering expertise is why we were able to do this and is why we were able to kind of justify the stockpile in the way that we did […], especially with structural materials […] you kind of need that structural expertise to understand what the end user needs, like what that end engineer of record needs and what's to understand to feel comfortable. I think that's the biggest piece, is that level of comfort is like the tricky part,"

In summary, contractors, and jurisdictions exhibit a comfort level in utilizing reused steel, contingent upon prior testing and certification by structural engineers. This contrasts with the reservations expressed by the engineers regarding trusting information from their counterparts. This trust dynamic reveals a potential need for standardization, and guidelines in the use of reused steel, particularly in ensuring cross-engineer reliability. This finding is relevant to our research, as it underscores the role of industry-wide certifications, standards, and guidelines as potential drivers for the widespread adoption of reused steel in design and construction. Moreover, the lack of trust among engineers suggests a potential barrier to promoting the reuse of steel in the AEC industry.

Engineer's perspectives on the constraints imposed by reused steel in the Design phase

Engineers consider that the use of reused steel could significantly shift the design phase, requiring a balance between optimization goals and the constraints imposed by available materials. According to the engineers, the incorporation of reused steel prompts a shift where engineers are compelled to create designs based on the available materials, indicating a departure from the traditional approach of designing first and then considering material usage. This suggests a reversed design process, emphasizing the adaptability of design to fit the available reused materials. As shared by a stakeholder:

"So instead of designing it and then saying what pieces can we use […] the process can kind of be flipped to say […] these are the pieces we have available. How should you layout the framing to accommodate those or to be able to use those best?"

This perspective highlights the dynamic interaction between design and material availability, challenging conventional linear design thinking. By designing around available materials, engineers may encounter constraints that could limit the achievement of design goals. This is illustrated by the statement,

"So just thinking structurally […] if you're given that upfront and designing around it, it might give you some design constraints where it might limit what the team's trying to accomplish with their design."

This discloses the delicate balance that engineers must navigate between design and the constraints imposed by reused materials. Moreover, engineers emphasize the need for over-optimization and overbuilding when working with reused steel. An engineer shares this sentiment with the following:

"We've got a W-27 by a 27-inch-deep beam available. That's the next largest size that's available […] And like our members are massive that we would install in our mezzanine, people would say like, why is your stuff so overbuilt? […] So, it sort of looks bad on the engineer whose job is to optimize, but instead you're having to over-optimize or overbuild to use existing steel."

This aspect introduces a layer of complexity, as engineers grapple with the tension between optimizing structures for performance and adhering to the constraints of available reused materials. In summary, engineers perceive that the use of reused steel introduces a significant disruption to the design process, requiring a delicate balance between design optimization goals, and the constraints imposed by the available materials. This finding is noteworthy for its implications on conventional linear design thinking, as well as the challenges associated with achieving both structural efficiency and adaptability in the context of reused steel.

EXPECTED CONTRIBUTIONS AND FUTURE WORK

The semi-structured interviews reveal a complex landscape surrounding steel reuse and associated decision-making within the AEC industry. Intellectual contributions address gaps in the existing literature and identify key implications for advancing steel reuse practices. While previous studies have explored potential barriers and enablers of reuse (Lu et al. 2020; Oyedele et al. 2014; Shooshtarian et al. 2020), this research delves deeper into characterizing perceived challenges and opportunities across stakeholders throughout design phases. As such, this work identifies uncertainties and information needs that should be addressed to facilitate the future adoption of reused materials in the building sector. The interplay between financial motivations and apprehensions underscores the nuanced nature of decision-making in the use of reused steel.

The research explores the relationship between costs and project phases, observing a closed-loop system indicating the potential for a sustainable and interconnected construction process and emphasizing the need for informed decision-making and resource management in the AEC industry. In addition, findings reveal the need to address (dis)incentives by suggesting the need for incentivized reuse, including subsidies or increasing the cost of waste disposal and tipping fees. The research also emphasizes the importance of innovation and technology development to facilitate steel reuse and the significance of collaboration for more effective initiatives.

Our exploration revealed a contrast of perspectives on reusing steel. Contractors and jurisdictions expressed confidence in reused steel upon certification by engineers, but engineers exhibited skepticism and a desire for personal validation, suggesting a potential need for standardization and guidelines to enhance cross-engineer reliability. Moreover, our research reveals that engineers anticipate a significant shift in the design phase with the incorporation of reused steel, emphasizing a departure from traditional linear design thinking to one that incorporates constraints from reuse in the design optimization process. Thus, a shift in the design phase has the potential to revolutionize the AEC industry's design, encouraging engineers to adapt their approaches based on material availability. This shift could foster innovation while necessitating careful consideration of sourcing, environmental impact, and regulatory compliance. Thus, the implications of incorporating reused steel extend beyond technical considerations to encompass, environmental, regulatory, and market dynamics, underscoring the importance of proactive planning and collaboration among stakeholders.

This study aims to bridge the perceptual gap between concerns and the pragmatic feasibility of steel reuse, contributing to a more informed and sustainable AEC industry. Future work should include a larger sample size that encompasses diverse perspectives from different regions. This will enable a more robust exploration and validation of the themes identified in our current study. In addition, future research could delve into the implementation of industry-wide certifications, standards, and guidelines to bolster trust and reliability in the utilization of reused steel, addressing the concerns articulated by engineers. In addition, future work can focus on strategies to optimize the design process when incorporating reused steel, balancing structural efficiency with adaptability to available materials. Another area of research can include an in-depth analysis of the market dynamics and a comprehensive lifecycle assessment to quantify the environmental impact of steel reuse, considering factors beyond cost, encompassing factors influencing resale value, market trends, and potential interventions to enhance market viability.

This preliminary analysis of stakeholder perceptions, the factors influencing acceptance or resistance to material reuse, and information needs is crucial to determining opportunities for expanded use and adoption in the AEC industry.

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